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BOMBAY- 1960
PART II

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INDIAN SCIENCE CONGRESS ASSOCIATION

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PROCEEDINGS
OF THE

FORTY-SEVENTH SESSION

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PART II

PRESIDENTIAL ADDRESSES

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Proceedings of the Forty-Seventh Indian Science Congress

PART II : PRESIDENTIAL ADDRESSES

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FORTY-SEVENTH INDIAN SCIENCE CONGRESS

BOMBAY, 1960

Congress President :—PROF. P. PARIJA, M.A., (CANTAB.), D.Sc., F.N.I.

PRESIDENTIAL ADDRESS

IMPACT OF SOCIETY ON SCIENCE

I am grateful to the members of the Science Congress Association for the honour done to me by electing me to be their President, although I realise at the same time how undeserving I am of that honour. It is perhaps in recognition of my long association with the Indian Science Congress in one capacity or another, because I am no longer an active worker in any branch of science, but only an interested observer at close quarters. Such a position has certain advantages of its own. A specialised scientific worker is like a man inside the forest whose vision is often limited to the tree while an interested observer is like a man outside the forest looking at the forest as a whole. He not only sees the beautiful foliage, flowers, fruits and the harmonious blending of colours, but is also likely to notice the spark that may spread the forest fires. He may also speculate on the factors that might have inhibited the growth of the forests in some parts producing undergrown areas.

What little a man like me may say will therefore be based on the musings of an interested observer who had been a humble worker inside the forest. During the few minutes at my disposal, I shall deal with one aspect of the relation between society and scientific progress. Scientific discoveries in various directions have been utilised so extensively for the advancement of social welfare in all its aspects that one is likely to overlook the restraining influence society had on science. Even today this influence is operating. Unless we guard against this, true scientific advancement may be hindered. It would be useful to know what these restrictions are so that one can guard against them in the interest of science.

From the time human beings began to take interest in the natural phenomena around them, they have been curious about their causes and have formed tentative hypotheses. The earliest presumption based on human experience has been that every phenomenon is the manifestation of an intelligent being. Hence an individual deity had been presumed for each particular phenomenon. Thus gods of rain, wind, fire and light had been conceived. Later on, these were synthesised into a universal godhead. When such hypotheses were consolidated into doctrines of faith, they hindered progressive thinking. Any dissent from the accepted doctrines was dubbed as heresy. We all know how free scientific thinking suffered in the West from doctrinaire orthodoxy and how the inhibitory influence has been overcome. As to the East in general, Whitehead in the course of his analytical study of the growth of science in Europe makes one observation about China, India and Iran which deserves our attention. He says :

"There have been great civilisations in which the peculiar balance of mind required for science has only fitfully appeared and has produced the feeblest result. For example, the more we know of the Chinese art, of Chinese literature, and of the Chinese philosophy of life, the more we admire the heights to which that civilisation attained. For thousands of years, there have been in China acute and learned men patiently devoting their lives to study. Having regard to the span of time, and to the population concerned, China forms the largest volume of civilisation which the world has seen. There is no reason to doubt the intrinsic capacity of individual Chinamen for the pursuit of science. And yet Chinese science is practically negligible. There is no reason to believe that China, if left to itself, would have ever produced any progress in science. The same may be said of India. Furthermore, if the Persians had enslaved the Greeks, there is no definite ground for belief that science would have flourished in Europe."

Whether the conclusion that these civilisations left to themselves would have produced any progress of science or not is a debatable question. The assertion that the peculiar balance of mind made only fitful appearance requires scrutiny. Before one can accept such a generalisation, one has to analyse the factors which have exercised influence on human thought in these civilisations. If these influences are eliminated, it is doubtful if the human mind in these countries would be different from that in any other part of the world. It is admitted that scientific thought did appear and contributions were made by these countries. There is no reason to believe that, given suitable conditions, such thought would not have continued without any break. The fact, however, remains that after a certain stage scientific progress stagnated. In our country we have evidence that in the early centuries of the Christian era, this country attained a leading position in scientific achievements in all directions. Thus, for example, during the period when Kalidas, the author of Shakuntala, lived, i.e. in the 4th and 5th century A.D., we find mention of many illustrious names. To name only a few, Nagarjuna, the physician, Varahamihira, the astronomer, Vararuchi, the grammarian and Amar Singha, the lexicographer, seem to belong to this period. These men were noted in their own branches of learning. Amar Singha in particular records in his lexicon careful observations on plants and animals and each synonym given describes a particular character or group of characters of plants and animals. There was, also an attempt at classification of living beings according to their habits and mode of reproduction. Our sculpture gives evidence of careful observation of the human and animal body and of the plant world. This period may be called the peak period of scientific thought and it extended over a few centuries, because the Chinese pilgrims, like Fa Hiyan and Houen Tsang speak highly of Indian medicine. It is recorded in the history of the Sui Dynasty that in early seventh century books on Brahmin Astronomical Manual, Brahmin Mathematics, Brahmin Calendrical methods and Brahmin Pharmaceutics were translated into Chinese. Not only this, the Hindus, like the Greeks, regarded Man as a part of the living world, though endowed with certain special qualities that they called *Dharma* while Europe still clung to the idea of special creation of man.

"Man", said Anaximander, "was produced in the first instance from animals of a different kind". According to the Hindus—

आहारनिद्राभयमैथुनं च
सामान्यमेतत् पशुभिर्नराणाम् ।
धर्मो हि तेषामधिको विशेषः
धर्मेण हीनाः पशुभिः समानाः ॥

Eating, sleeping, fear and reproduction men have in common with animals. Dharma is the only speciality of man. Without "Dharma" man is like a beast.

If these lines of thought had been pursued unhindered, it is imaginable that true scientific progress would have followed. We have now to see why further progress stopped. While progress was being made in advancing knowledge through observation and deductions and reached the height in the early centuries of the Christian era, there was running concurrently another line of thought, namely that knowledge can be acquired through intuitive perception. This power of intuition is either god-given or developed through prescribed exercises. Naturally such power was supposed to be inborn in a few. Those endowed with intuitive power prescribed certain exercises for the attainment of this superior quality and it was open to any man to follow the prescribed path to gain the intuitive power. This led to the cult of the sage or Preceptor and the disciple. According to this cult the disciple had to follow implicitly the path shown by the Preceptor. The result was that thought was canalised and unrestricted free-thinking which is so necessary for scientific progress, was hindered. Of these two means of acquiring knowledge, the one by developing intuitive power evidently got the upper hand and the other, namely that by observational deductions was superseded. The reason for this is not clear—possibly the traditional tendency to seek the ultimate by meditation without physical exertion might have been the cause. The result was that free-thinking was restricted. Now and then one comes across instances of revolt against such restriction on thought but these did not change the main current.

It is not contended here that this line of thought has not produced anything good. By pure logical deductions, the ancient sages have arrived at conclusions which are similar to the conclusions arrived at by scientific methods. As an example, may be cited the atomic theory of Nyayavaisesika which deduces the existence of atoms from the known divisibility of perceivable material objects—a divisibility which must terminate at some stage. The terminal stage in this process of division gives the atom which is simple and partless. However, one effect of this cult was that men's mind turned inwards and all thought was directed towards self-improvement to gain the highest bliss, namely, to have communion with divinity. The surrounding world was considered unreal. So long as the sage remained the perfect man, no harm was done. Unfortunately nothing human remains stationary. The perfect man did not remain at the highest level and degeneration set in. All thought became self-centered and natural phenomena were observed as omens for divination based on faulty generalisation from insufficient data. Astrology, that pseudo-science based on empirical generalisations comes to one's mind as an example of such divination. When such ideas grip men's minds, all observations are biased and not scientific.

So far as one can gather a similar line of thought was developed in China in Taoistic philosophy. This line of thought became wide-spread with the help of the preachers belonging to all schools. This is not peculiar to China or India. It is stated that in Greece, Science declined and ethics and metaphysics prospered on account of Sophists and itinerant lecturers and discussions. According to Casson, these lecturers were men without any specialised knowledge and they gravitated towards the kind of philosophy which had no need for any raw material other than the behaviour of men among themselves. This sort of canalisation of thought making it egocentric appears to be one of the main factors which stood in the way of scientific advancement.

In addition to this and perhaps as an offshoot of this mode of thinking, in our country there were restrictions put by authoritarian injunction on the intellectual pursuits of men. As an example, one may cite Manu's classification of men into categaries confining each to a particular sphere of activity with heavy penalties for transgression. Although Manu lived long before the peak period indicated earlier, and the original work did not prescribe rigid demarcation of boundaries between different categories, these prescriptions by Manu underwent changes in course of time and by the period we are talking about or even before this period boundaries got baked into rigid lines and castes became immutable. These inhibitions naturally stunted the natural propensities of capable men. There are instances in which severe punishments have been inflicted if a man transgressed from his assigned sphere.

There was another factor which seems to have universal application and that is the absence of a sense of security. Progressive thought is only possible when people have a sense of security. At the peak period of intellectual development there seems to have been peace and prosperity in our country. Soon, however, internal strife and foreign invasions, especially by the Huns, destroyed peace in the country and security of the people. Invaders whether they are barbarians or civilised people, seldom attach any value or pay any attention to the cultural achievements of the conquered country. The Romans did not pay adequate attention to Greek achievements nor did the foreign rulers of India attach much value in the beginning to our culture. When there is lack of peace and security and no encouragement from the rulers, all intellectual activity is either stopped or goes into hiding, so to speak, and confined to pure literary work as opposed to scientific activity.

Internal strife and foreign invasion seem to have had such effect on the scientific advancement in our country after the peak period. The Ionian and Greek science seems to have met with similar fate after foreign invasions. The "Athenians and most other Greeks", says Casson, "had become introspective and self analytic. To some extent this might have been due to the incidence of the Peloponesian war which, like all wars, limited the possibilities of genuine research and drove men into themselves. Science was, for the time being, overwhelmed". China also must have experienced such difficulties after repeated foreign invasions.

Thus we see that in our country and in other eastern countries, so far as one can see, the two main inhibitive factors against free thinking have been the authoritarian imposition of dogmas and foreign invasions. The former canalised human thought while the latter created a sense of insecurity and subdued the free-play of human curiosity which is the basis of all scientific activity. In the West also these factors were operative upto a certain period. Upto that point there was not much difference between the West and the East so far as the scientific thought was concerned. It was not a question of lack of balance of mind. The channel of thought was directed by external forces.

In Europe certain historical events occurred which led to intellectual freedom. The chief of these were the industrial revolution, voyages of discovery and the conquest of Byzantium by the Turks. Behind the industrial revolution was the desire to emulate the quality of imported goods from India and China and to produce them in large quantities so that trade might expand. This attempt at production led to empirical experiments in technology. These empirical experiments led ultimately to scientific experiments. On the other hand, the voyages of discovery were actuated by the motive of discovering the sources of the imported goods and thereby promote trade. Incidentally from these voyages were brought back a mass of information and materials which, when studied, tended to shake the faith vested in dogmas. This process was aided by the greater access to Greek literature when on the fall of Constantinople Greek culture with its traditional free-thinking moved westward into Europe.

Similar events did not occur in our country. The reasons are not far to seek. The social organisation and the economic system were such that the incentive for revolutionary change did not exist. Different circumscribed groups or classes were enjoined to stick to the production of the goods assigned to them. Improvement of the process of manufacture was confined to the inventive ability of that group. The products were considered superior to those of other countries. Although contact with the outside world by land and by sea had been long established, and abundant evidence of such contact exists even today in far off lands, these voyages do not seem to be as fruitful as those in Europe. Reasons appear to be two-fold. Of the two classes of men who undertook voyages, one class had the mission of spreading spiritual doctrines. Perhaps the majority of this class did not come back to the homeland and their experiences were lost to the country. The other must have belonged to the class which was traditionally and religiously enjoined to follow their particular profession and hence had limited vision. Even then these contacts with the outside world were so disturbing to the orthodox at home that a ban was placed on voyages beyond the seas. Those who undertook voyages were put in the same category as convicts and perjurers and were banned as social outcastes by Manu.

समुद्रयायी वन्दी च तैलिकः कुटकारकः
एतान् विगर्हिताचारानुभयत्र बिवर्जयेत ।

Even journeys to the eastern parts of India were prohibited except for the purpose of pilgrimage.

Apart from these considerations, people seem to have developed a superiority complex which does not encourage perceiving or receiving anything good in other civilisations. A Chinese pilgrim records that at a farewell gathering at Nalanda, the Indian monks asked him to stay on in India as in his country there was nothing worth going back to. If this was the attitude of those devoted to study, one can imagine what would have been the attitude of the others.

Other peaceful cultural contacts were neither many nor lasting to have any influence on the mental attitude of the people. There was some exchange of thoughts and ideas with Greece but there does not seem to have been any change in the intellectual attitude.

When, however, there was lasting peaceful contact with the free-thinking world, an age of intellectual freedom was ushered in. Those Indians who responded to this liberalising influence have made notable contributions to scientific advancement. Freed from the restrictive social influences, the Indian mind is equally capable of scientific thought as any Western mind. This can be said of all eastern peoples.

We have so far analysed the inhibitory influence society had imposed on scientific advancement. Now let us examine whether such influences are operative today. Although these influences may not appear in the crude forms of the bygone days, yet it will be seen that they do exist today.

Group-consciousness based on race, religion, language and social ideologies has raised its ugly head and has led to various conflicts all the world over. In our country despite efforts to the contrary, there is a recrudescence of narrow group-consciousness. When group-consciousness makes its appearance, it leads to grooved thinking. We have already seen that such canalised thought is not conducive to scientific advancement. On the other hand, it generates hatred and exclusiveness. In such circumstances, the rivalry and fear-complex in the antagonistic groups actuate them to develop means of self-defence against apprehended conflicts. The scientific discoveries already made are utilised to perfect weapons of self-defence. The spectacular utilisation of nuclear energy is an example to the point. During the process of perfection of such weapons, an astounding quantity of scientific data and information has been gathered as a bye-product. No doubt these data and information are valuable for fundamental science, but it is permissible to envisage that if there had been co-operation between the various groups engaged in such activities and if they had been actuated with the motive of elucidating the ultimate foundation of natural phenomena, greater success would have resulted. In place of fear and rivalry, the knowledge obtained would have been shared by the whole human race and would have been applied for the welfare of the whole mankind. It will not be out of place to quote what Bertrand Russell says on this subject. He says—

> "The creation of satellites has given pleasure to schoolboys and statesmen, marred only, for the West, by the fact that the first satellite was Russian. As yet, satellites are small ; but it is not to be supposed that they will remain so. They do not at present carry weapons of offence, but militarists everywhere hope that they will carry such weapons before long. By means of electronic computers, they can be timed to rain death upon enemy regions, while suspending this useful activity during their passage over friendly territory. Such weapons will be enormously expensive, but on each side it will be argued ; 'if the enemy may have them, we must set about having them too.'."

He goes on to say, "But I am afraid that it is from baser motives that people are willing to spend enormous sums involved in making space-travel possible".

We have seen earlier that a sense of insecurity and invasions were responsible for making people self-analytic and hence scientific thought was hindered. The same feeling in another form is operative today. Some of the ablest minds are being diverted to channels not leading to fundamental scientific advance.

There is another undesirable effect of confining one's thought to the narrow limits of a group. Science and literature require encouragement and patronage. Group-consciousness leads to limit such patronage to talents inside the group. Such talent may be of the highest quality judged by any standard but it may also be of a mediocre quality. Confining patronage to the latter type of talent means that we are satisfied with the minimum while a broader outlook can secure the best available type as the object of patronage.

We have so far seen that one of the limiting factors, namely, the one generated by a sense of insecurity and desire for self-defence, is operative today though not in the same crude form as in the past. Let us see if the second one, namely, imposition of doctrinal dogmas on men's mind is also operative today. In some parts of the world social revolution has led to the reorganisation of society. One of the main arguments for such reorganisation is that, given the same nurtural environment, every human being can attain the same intellectual height irrespective of hereditary limitations. In other words, qualities acquired under environmental influences during short exposure to such influences become permanent and heritable. On the other hand, the results of prolonged biological investigations suggest that nurture can only bring about the development of hereditary potentialities. No one denies the possibility of the hereditary composition of the individual being altered by environment provided the environmental conditions are so powerful that they affect the nature and composition of the carrier of hereditary characters. But to say that short exposure of the individual to altered environment during the life time would produce heritable changes is to discredit all experimental evidence on heredity. In order to emphasise the overall importance of inheritance of acquired characters, some scientists have made attempts by uncritical experiments to produce evidence to that effect. According to Julian Huxley, "it is less a branch of science comprising a basis of facts than a branch of ideology, a doctrine which it is sought to impose upon facts". Whether such attempts are designed to secure the goodwill of the powers that be or they are the result of directives from above, the influence of doctrinal imposition on scientific investigation is clearly indicated. What is happening in one part of the world may happen in any other part.

Man is naturally prone to impose his ideas on others. If such attitude is supported by age old tradition as in our country, it may become a common custom. In our country and possibly in the eastern countries in general, the danger of the revival of authoritarian tendency is real. Rude awakening to the reality of this danger comes when a sooth-sayer or miracle man attracts to his door even men with scientific training. Recent political happenings might give an impetus to such revival as a reaction against western political domination. One already sees signs of such harking back to the past. This in itself is not condemnable but if it revives authoritarian domination, scientific thought is in danger.

In this brief account the inhibiting influences of society on science are indicated as one sees them. Men of science all the world over should guard against such obstacles if probing into the mysteries of nature in search of truth, is to continue unhindered. Only by co-operation and not by unhealthy competition can the mysteries of nature be unravelled by the men of science and through the application of their discoveries the welfare of the mankind will be assured.

SECTION OF MATHEMATICS

PRESIDENT: PROF. V. GANAPATHY IYER

Presidential Address

THEORY OF APPROXIMATION

Fellow Mathematicians, Ladies, and Gentlemen,

I feel it an honour that I have been given the opportunity to preside over the Mathematics Section of the Indian Science Congress Association. The Mathematical part of the address gives a brief account of the theory of Approximations. Before proceeding to it, I desire to make a few general observations.

It is a regrettable fact that interference and influence of politicians and other non-academic persons endowed with authority in shaping the course of higher education in this country have attained unhealthy proportions. As I already pointed out on another occasion the experienced teacher is allowed practically no voice in the matter. Even the University Grants Commission supposed to guard zealously the autonomy of universities has not escaped the temptation to impose its decisions on universities with financial sanction behind it. As, an instance, it was reported in the papers, that the recent decision to have a minimum of 180 working days exclusive of examination days in universities had to be implemented by all the universities because of the financial sanction behind it. If the report is true, it reveals a sorry state of affairs. I am not discussing the merits or demerits of increasing or decreasing the number of working days. I say that this is a matter to be decided by the universities themselves. As a matter of fact, a true teacher or student has no holidays. The apparent holidays are intended for the teacher to acquire further knowledge and for the student to assimilate what he has learned. To equate teaching work and learning to man-hours, to say the least, exhibits appalling ignorance of the nature of academic work.

Next turning to the state of development of Mathematics in this country, I have already pointed out in my Presidential addresses to the Indian Mathematical Conference, that we are indeed very backward compared to Mathematically advanced countries. With a view to increase the pace of higher research in mathematics, the Indian Mathematical Society has appealed to the Central Government to open National Institute for research in Mathematics on the lines of the National Laboratories in other sciences but no concrete step has been taken so far. On the other hand, the Govt. has taken a retrograde step in effectively closing down the Ramanujan Institute at Madras. It is too late in the day to expatiate on the use of mathematics to other sciences. It is an every day occurrence that in scientifically advanced countries, even apparently abstruse developments in Mathematics have found applications in Science and Technology and it is now well realised in such countries that no fundamental progress can be made in Science and Technology without a corresponding advance in Mathematics. In this country, the average scientist has not recognised the above fact fully. With rare exceptions, the Indian scientist's attitude to mathematical development in this country is very much like the psychology of the boy who, when asked how he was able to secure his food, promptly replied that the granery in his house produced the grain, the servant husked, it, his mother cooked and he ate. Even among the few mathematicians in this country, there is not a general awareness of the need to develop the subject in its higher reaches and some of them exhibit the unfortunate attitude that what they work on or approve of is the only type of mathematical research worthwhile and all other work is trivial. This shows a lack of humility and failure to recognise one's limitations essential to intellectual honesty and real progress. I have tried to focus your attention on some of the defects in our educational system and in the state of development of Mathematics. It behoves all interested in the sound progress of these facets of the nation's activity to find suitable remedies for the situation.

I shall now give a brief account of the theory of approximations. The secret of the power of Mathematics in its application to other sciences is due ultimately to the fact that Mathematics in its very nature is the science of thought. The developments in Mathematics are becoming more and more abstract and at the same time many of these have found applications in Science and Technology. When a theoretical solution to the mathematical formulation of a scientific problem is to be tested against experimental results, the solution obtained have to be approximated to before the solution would be of any use for the purpose of testing. It is in this connection that the theory of approximations become important. Once the notion of approximation enters a discussion, it is necessary to know the error involved in taking the approximate value for the actual theoretical value. Usually an estimate of the maximum error involved could be made. For instance, if a function possesses two derivatives in an interval round $x = a$, the error involved in taking $f(a+h)$ equal to $f(a)+hf'(a)$ cannot exceed numerically $M|h^2|/2$ where M is an upper bound of $|f''(x)|$ in an interval round a containing a and $a+h$. This is one of the simplest cases. But in many applications no such estimate may be possible. We have to be satisfied with finding an approximation which is the best possible in some specified sense, that is, the error involved in some specified manner is the minimum possible in making the approximation. This leads to the theory of best approximations—a general problem which has attracted the attention of many well known mathematicians. The formulation of the problem of best approximation is best expressed in the language of normed vector spaces.

NORMED VECTOR SPACES

A collection E of elements $x, y, z...$ is called a vector space over the complex number field if an operation of addition $x+y$ is defined on E for which E forms a commutative group and a multiplication by complex numbers a is defined so that $a(x+y) = ax+ay$, $a(bx) = b(ax) = (ab)x$, $1.x = x$ and $0.x = \theta$, the zero element of the additive group. A non-negative number $\| x \|$ defined over E is called a norm on X if $\| x \| = 0$ if and only if $x = \theta$, $\|ax\| = |a| \, \|x\|$, and $\|x+y\| < \|x\| + \|y\|$. E is said to be strictly normed if $\|x+y\| = \|x\| + \|y\|$ if and only if $x = ay$, $a \geqslant 0$. The vector space E over the complex field on which a norm is defined is called a normed vector space and if E, with the metric $\|x-y\|$, is complete it is called a Banach Space. If an inner product (x, y) is defined on E such that $(x, x) \geqslant 0$ and $= 0$ if and only if $x = \theta$, $(x, y) = \overline{(y, x)}$, $(ax, y) = a(x, y)$ and $(x+y, z) = (x, z)+(y, z)$, then it can be shown that $(x, x)^{\frac{1}{2}}$ is a norm on E and E is strictly normed. E with this norm when complete is called a Hilbert Space.

The space of all complex valued continuous functions on a closed interval or a bounded closed point set in the complex plane is a Banach space with norm of a function f equal to the l.u.b. of $|f|$ over the domain of definition. The finite dimensional Euclidean spaces are Hilbert Spaces over the real number field. The set of all square integrable functions over a measure space is a Hilbert Space with the integral of $f \bar{g}$ as the inner product (f, g). Again, the set of all complex sequences $x = (x_n)$ with $\Sigma |x_n|^2$ convergent and inner product $(x, y) = \Sigma x_n \bar{y}_n$ is a Hilbert Space.

THE PROBLEM OF BEST APPROXIMATION

The notion of best approximation can now be formulated as follows. Let E be a normed vector space. Let $F \subset E$ be a specified subset of E, and x an element of E. It is required to find an element $y \epsilon F$ such that $\| x-y \|$ is the least possible. Then we call y the best approximant to x in the subset F. The questions that naturally arise in this connection would be the existence, uniqueness and the specification (when it exists) of the best approximant. The most important case arises when F is a linear subspace of E. In this case it can be shown that if E is a complete Hilbert Space, F a closed subspace, then for any $x \in E$, there exists a unique best approximant. In general, if E is a normed space and is strictly normed, the best approximant if it exists will be unique but for a general normed (even complete) space it is not always possible to assert the existence of the best approximant when F is a closed subspace. But in one important case, namely, when F is a finite dimensional subspace of E, the existence of a best approximating element always can be proved. Explicitly stated, the problem reduces to finding the values of the complex numbers (or parameters) a_i, $i = 1, 2, \dots n$, such that for a given x and a given finite number x_i, $i = 1, 2, \dots n$, of elements of E, the norm $\| x - \sum_1^n a_i x_i \|$ is the least. Most of the specific results obtained in the theory of best approximations deal with this last case. We briefly mention a few of these results.

Consider the space of continuous functions in a closed interval $[a, b]$ normed by the l.u.b. of the modulus of the function over $[a, b]$. Consider the linear subspace generated by $1, x, x^2, \dots, x^n$. This is the set of polynomials of degree not exceeding n. The best approximation theorem now asserts the existence of a polynomial $P_n(x)$ of degree n for a given continuous function $f(x)$ in $[a, b]$ such that the $\underset{a \leqslant x \leqslant b}{\text{l.u.b.}} |f(x) - P_n(x)|$ is the least. It can be shown that the solution is unique. When $a = -1$, $b = 1$, $f(x) \equiv 0$ identically, the corresponding monic polynomials known as Tchebysheff's polynomials are given by the formula

$$P_n(x) = (1/2^n)[(x+\sqrt{x^2-1})^n+(x-\sqrt{x^2-1})^n]$$

which can be put in the more elegant form $P_n(x) = \cos n\theta/2^{n-1}$, $x = \cos \theta$.

The problem discussed in the last paragraph has been investigated under a more general setting. Let $f(x)$ and $s(x)$ be continuous in $[a, b]$. Consider. $Q(x) = s(x)\, R(x)$ where $R(x)$ is a rational function, the degrees of the numerator and denominator polynomials being given. It is required to determine $R(x)$ so that $\max_{a \leqslant x \leqslant b} |f(x) - Q(x)|$ is least. This problem has been completely solved (see the reference at the end). When $s(x) \equiv 1$ and $R(x)$ is a polynomial we get back to the situation described in the previous paragraph.

The theory of best approximations explained above is a special instance of the general extremal problems abounding in every branch of mathematics and its applications. The calculus of variations deal exclusively with such problems. The variational principles in Mechanics are instances of the problem in Applied Mathematics. I mention here one or two interesting results closely allied to the ideas of best approximation.

Consider the class B_d of all integral functions of exponential type not exceeding d and bounded on the real axis so that $M(|f|)$, the l.u.b. of $|f|$ of the real axis is finite. Then a result due to S. Bernstein states that $f'(z)$ belongs to B_d and $M(|f'|) \leqslant dM(|f|)$, the equality holding if and only if $f = ae^{idz}+be^{-idz}$, these latter constituting the set of extremal functions for the problem. For the Weierstrass' non-differentiable function $f(x) = \Sigma a^n \cos(b^n x)$, $0 < a < 1$, b an odd integer > 1, the sequence of partial sums is the trigonometric polynomials of best approximation of the corresponding order.

The result mentioned at the end of the last paragraph is an instance of the problem of approximating to periodic functions by trigonometric polynomials, an expression of the form $a_0 + \sum\limits_1^n (a_k \cos k\theta + b_k \sin k\theta)$ being called a trigonometric or harmonic polynomial of order n. If we take any normed linear space of functions of one variable with period 2π which include the trigonometric functions $\cos n\theta$ and $\sin n\theta$, $n = 0, 1, 2 \ldots$, the general problem of best harmonic approximation reduces to the problem formulated at the beginning. If the space be the class $L(0, 2\pi)$ of measurable functions with finite Lebesgue integrals, the norm being $\int\limits_0^{2\pi} |f|\, dx$, the problem reduces to finding the harmonic polynomial $T_n(\theta)$ of order n such that $\int\limits_0^{2\pi} |f(\theta) - T_n(\theta)|\, d\theta$ is minimum. If we consider the class $L_2(0, 2\pi)$ of square integrable periodic functions with period 2π, we have to seek $T_n(\theta)$ such that $\int\limits_0^{2\pi} |f(\theta) - T_n(\theta)|^2 d\theta$ is minimum. Instead of periodic functions we can consider the general class $L_2(a, b)$ of square integrable functions in any finite or infinite interval and seek the polynomial of minimum deviation for a given degree n. The principle of least squares belong to this category of results.

CLOSURE THEOREMS

The next problem in the theory of approximation is to ascertain when one can approximate to a given function of a class in terms of functions belonging to a given class within any given degree of approximation. In terms of normed vector space, this is equivalent to ascertaining when a given subset F of a normed space E is dense in E. The most important case arises when F is a linear subspace generated by a given sequence (x_n), $n = 1, 2, 3 \ldots$ of elements of E. The problem then reduces to finding conditions on the sequence (x_n) so that every element in E can be approximated as closely as one likes by finite linear combinations of the elements of the sequence. A sequence having this property is said to be fundamental or closed in E. Criteria for a sequence to be closed are known as closure theorems.

Weierstrass' famous theorem that every continuous function in an interval can be uniformly approximated to by polynomials now becomes the closure theorem that the sequence of functions x^n, $n = 0, 1, 2\ldots$ is closed in any space of continuous functions of one variable. This implies also that the minimum deviation corresponding to a polynomial of best approximation of degree n tends to zero as $n \to \infty$. An interesting generalisation of this theorem is due to Muntz. Let x^{p_i}, $p_i \geqslant 0$, $p_i \to \infty$ as $i \to \infty$, be a sequence of powers of x. A necessary and sufficient condition that this sequence is closed in the space of Continuous functions in $[0, 1]$ is that $\Sigma 1/p_i$ is divergent. Under the same conditions it can be shown that the sequence is closed in $L(0, 1)$ or $L_2(0, 1)$. The trigonometric functions $\cos n\theta$, $\sin n\theta$, $n = 0, 1, 2\ldots$ is closed in the space $L(0, 2\pi)$ of periodic integrable functions or $L_2(0, 2\pi)$ of square integrable functions. It is also closed in the space of continuous periodic functions with period 2π. Weiner's famous tauberian theorem is based on the closure theorem that in the space $L(-\infty, \propto)$, the set of translates $f(x+h)$, f given, h varies, of a function of the space will be closed in that space if and only if its Fourier transform $\int\limits_{-\infty}^{\infty} f(x)e^{iux}\, dx$ is never zero for real u. More generally, if F is any subset of $L(-\infty, \infty)$, the set of translates of the functions of F will be closed if and only if the set of Fourier transforms of the functions of F have no common real zero. In the space of uniformly almost periodic functions in $(-\infty, \infty)$, the set e^{itx}, as t takes all real values, is closed. Let c_k be a sequence of complex numbers, no two of which are equal and none lies on the real axis. Then the sequence of fractions $1/(x-c_k)$ is closed in the space C_∞ of continuous functions in $(-\infty, \infty)$ which have finite equal limits as $x \to \infty$ and as $x \to -\infty$, if and only if the series $\Sigma\, I(c_n)/(1+|c_n|^2)$ taken over those c_n for which $I(c_n) > 0$ and $I(c_n) < 0$ both diverge. A large amount of work has been done in the subject of closure theorems and many distinguished mathematicians have been attracted by the subject. In a separable complete Hilbert Space, one can formulate a general elegant result. Let E be a complete and separable Hilbert Space. Two elements x and y are said to be orthogonal if $(x, y) = 0$. An element is said to be normal if $(x.x) = 1$. The result mentioned now can be stated by saying that in such a space there always exists a closed sequence of orthonormal elements, that is, there exists a sequence (x_n) of elements closed in E such that $(x_n, x_m) = 1$ or 0 according as $n = m$ or $n \neq m$. Moreover every element x can be written as $x = \Sigma(x, x_n)\, x_n$ in the sense that the sequence of partial sums of the series converge in E to the element x.

THE TECHNIQUE OF APPROXIMATION

Except in simple cases where analytic expressions are available for approximation to a function or number like the series for the trigonometric functions and for π and e, the process of approximation itself has to be chosen to suit the needs of the problem. Often the general situation is that the nature of the function itself is unknown or very complicated but its values at a specified set of points are known or can be ascertained by experiment the result of which is to be compared with the theoretical solution. In such cases two broad methods are used for approximation.

INTERPOLATION

Let $f(x)$ be a function defined in an interval (a, b) and let x_i, $i = 1, 2, \ldots, n+1$, be $n+1$ distinct points in (a,b) where the values $f(x_i)$ of f are known or can be ascertained by experiments pertaining to the problem. For each i, there is a unique polynomial of degree n taking the value one at $x = x_i$ and zero at the remaining n points. Let $L_i(x)$ denote this polynomial. It is easily seen that $L_i(x) = \prod_{\substack{j=1 \\ j \neq i}}^{n+1} (x-x_j)/(x_i-x_j)$. Then $P_n(x\,; f) = \Sigma f(x_i)\, L_i(x)$ is the unique polynomial of degree n which takes the value $f(x_i)$ at $x = x_i$. If for each n, the $(n+1)$ points x_i are suitably chosen and n made to tend to infinity then under suitable hypothesis on $f(x)$, the polynomials P_n may converge (pointwise or in some other sense according to the problem under consideration). In this case, for n large enough, P_n represents a close approximation to $f(x)$. This method is known as the method of interpolation —a topic which has been widely investigated.

ORTHOGONAL POLYNOMIALS :

Associated with every non-negative integrable function $w(x)$ in an interval I there exists a unique sequence $P_n(x)$ of polynomials with the property that $\int_I w(x)\, P_n(x) P_m(x) dx = 1$ or 0 according as $m = n$ or $m \neq n$. This sequence is called the orthonormal sequence of polynomials associated with $w(x)$ usually called a weight function. When $w(x) \equiv 1$ in $[-1,1]$, the polynomials are constant multiples of the Legendre polynomials. When $w(x) = e^{-x^2}$, in $(-\infty,\infty)$, the polynomials obtained are the Hermite polynomials. Various types of useful orthonormal set of polynomials have also been investigated by many mathematicians. Now, with a function $f(x)$ with suitable properties in (a, b) we associate the orthonormal series $\Sigma c_n p_n(x)$ where $c_n = \int_a^b f(x) w(x) P_n(x) dx$ and investigate its convergence towards $f(x)$ in a suitable sense. Under these conditions, sufficiently large number of terms of the series will give the required approximation to $f(x)$. When f belonging to a specified class is given by its values at a discrete set of points in (a, b), the value of c_n itself is to be approximated by replacing the integral by approximate sums.

The technique of using these methods, estimation of the error involved in these approximations, use of mechanical calculators as aids for this purpose all now go under the name of '*Numerical Methods*' in Mathematics and this branch by itself has grown so vast as to require a life time of specialisation. By these methods based on the theories sketched earlier and the use of more and more rapid calculators, the problem of comparing the theoretical solution to a scientific hypothesis with experimental results is becoming more and more easy.

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SECTION OF STATISTICS

PRESIDENT : DR. C. RADHAKRISHNA RAO, Ph.D. (Cantab), F.N.I.

Presidential Address

MULTIVARIATE ANALYSIS : AN INDISPENSABLE STATISTICAL AID IN APPLIED RESEARCH

1. INTRODUCTION

Some of our past presidents had selected for their addresses topics of philosophical interest or had reviewed recent trends in statistics. A few presented current statistical theories of inference, while others explored special techniques in fields of application. I am inclined to fall in line with the last group, although with one difference. Instead of choosing a particular field of application I propose to consider that body of statistical methods generally known as multivariate analysis and discuss its usefulness in applied research in a variety of fields.

Research workers are often satisfied with univariate techniques in the reduction and interpretation of their data. Multivariate methods, though more appropriate in certain situations, are not adopted mainly because of the complexity of the procedures involved, which make the research workers dependent on specialists who can understand the situation and prescribe, with some success, suitable formulae, and also on computers capable of receiving complicated instructions for numerical work.

Statisticians themselves are not unanimous in their views about the role of multivariate analysis. Fortunately, however, the controversies have not been of the traditional type we are used to in statistics, leading to the creation of rival schools of thought.

A few statisticians are optimistic and think that multivariate analysis 'has reached a fairly stable position theoretically and a considerable service might be done if further discussion were attempted of its use in different fields'.[1] Some doubt the real superiority of multivariate methods and consider the examination of individual measurements by simpler univariate methods 'as an *essential step*, which can be supplemented by more elaborate multivariate analysis when this appears feasible and necessary'.[2] A few others are critical of particular applications and regard some papers on multivariate analysis as providing 'new outlets for mathematical theory without materially assisting scientific research' and suggest 'the need to examine carefully their relevance to the interpretation of experimental and observational data.'[3] We also have the critical remark addressed to the statisticians that 'we go multivariate when we do not understand the practical situation.'[4]

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[1] from private correspondence with Prof. M. S. Bartlett.

The subject is not, therefore, without those controversial elements which are perhaps necessary for the proper development and refinement of techniques.

It must be remembered that a tool, although it may figure prominently for some time in literature, will condemn itself if its application is subject to severe limitations or if its practice misleads the research workers. Introduced and developed by pioneers like Galton, Pearson, Fisher and Mahalanobis for application in biometric studies and by Spearman and Hotelling in psychometric studies, multivariate analysis has now evolved itself as an essential scientific aid in applied research.

2. MULTIVARIATE ANALYSIS AS TECHNIQUES OF PREDICTION

In order to emphasize the practical importance of multivariate analysis, I would like to introduce the subject as essentially a body of techniques to be used for predicting one or more what we may call criterion variables (c.v.'s) with the help of others known as predictor variables (p.v.'s).

The criterion variables may have nominal, ordinal or interval scale of measurement and they may be observable or hypothetical, while the predictor variables may have nominal or interval scale (see footnote 6).

The general theory of regression subsumes, as a rule, all prediction problems but differences exist in the computational procedures for different situations distinguishable by the scale types of criterion and predictor variables. Chart 1 shows the different possible combinations and, wherever available, the statistical terms used to describe the computational procedures.[5]

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[2] Yates and Healy (1951), *Nature*, 168, p. 1116.

[3] Finney (1956).

[4] from an after dinner talk by Prof. J. Tukey.

[5] Lubin (1950) considered the two possibilities, quantitative and qualitative for each of predictor and criterion variables.

CHART 1 : MULTIVARIATE ANALYSIS AS PROCEDURES FOR PREDICTION

Scale of predictor variable	Scale of criterion variable [6]			
	Nominal	Ordinal	Interval	
			observable	hypothetical
Nominal	Contingency tables	?	Least square theory	Latent structure analysis
Interval	Discriminant function	?	Multiple regression	Genetic selection, Factor analysis

For the combinations where question marks are placed there appear to be no standard statistical methods, although such situations are sometimes met with in practice (see section 7 of this paper for a discussion of the ordinal-interval combination).

It is not suggested that other possibilities do not exist, such as using mixtures of nominal and interval scale variables or even using an ordinal scale variable for predicting a c.v. The scheme indicated in Chart 1 is adopted only as a suitable framework for discussing some of the different procedures available in the literature. It must be also mentioned that for a given combination of p.v. and c.v., a particular method indicated is applicable only in some special situations.

I shall consider the various methods mentioned in Chart 1 one by one, briefly review the present position and make some suggestions for further refinement of the method or enlarging its scope. Two of the methods, contingency tables and least square theory, are well known and need no further discussion in the present context.

3. MULTIPLE REGRESSION

(C.V.'S AND P.V.'S OBSERVABLE ON INTERVAL SCALE)

The theoretical development of the subject of multivariate analysis originated with the concept of regression, introduced and used by Francis

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[6] Measurements are generally classified into four distinct scales. Numbers, names or other symbols used simply to classify an object, person or characteristic constitute a *nominal* or a classificatory scale. The only relation that can exist between elements on a nominal scale is *equivalence* by which the various elements can only be identified as belonging to different groups. If besides equivalence the relation $>$ holds between the identifying symbols, then a rank ordering is possible in which case the measurement is said to be on an *ordinal* or ranking scale. If between measurements on an ordinal scale comparable distances can be defined we have an *interval* scale. An interval scale further having a true zero point for its origin is called a *ratio* scale. For example if my friend is described as (i) South Indian, (ii) Under Secretary, (iii) four inches taller (then I am), (iv) weighing 98 lbs., and (v) having 12 children, then we have 5 measurements on him of which (i) is on a nominal scale, (ii) on an ordinal scale (in government hierarchy), (iii) on an interval scale, and (iv) and (v) on a ratio scale. A measurement on a ratio scale also belongs to an interval scale and the statistical procedures described in this paper are same for both.

Galton (1889) in his famous study of natural inheritance. Establishing a linear relationship between the average stature of sons and the stature of the Mid-Parents[7] he came to the following conclusions[8], which can be equally true for many other characteristics. 'Sons do not on the average resemble their Mid-Parents except when they are mediocre... The more bountifully the parent is gifted by Nature, the more rare will be his good fortune if he begets a son who is as richly endowed as himself... although it is true that children of a gifted pair are much more likely to be gifted than children of a mediocre pair... The ablest of all the children of a few gifted pairs is not likely to be as gifted as the ablest of all children of a very great many mediocre pairs. The number of individuals who are nearly mediocre is so preponderant, that an exceptional man is more frequently found to be the exceptional son of mediocre parents than the average son of very exceptional parents'.

Karl Pearson and Udny Yule, and R. A. Fisher (who provided an exact statistical theory) extended the concept of regression for predicting a variable utilising a number of other variables. Some of the purposes for which this method is applied are considered in this section.

Prediction in an individual case : An early example in India of the use of multiple regression is in the prediction of monsoon rainfall well in advance of its onset, which is very important for an agricultural country like ours. Gilbert Walker (1914) was able to establish a good correlation between total rainfall in India with preceding weather conditions outside India. The regression equation given for this purpose in 1910 was

$$\begin{aligned}\text{Monsoon rainfall in India} = &-0.20 \text{ (snowfall accumulation)}\\ &-0.29 \text{ (Mauritius pressure)}\\ &+0.28 \text{ (South American pressure)}\\ &-0.12 \text{ (Zanzibar rainfall).}\end{aligned}$$

which, as you may observe, has some baffling predictor variables. The real test of a regression equation is its performance, i.e., 'waiting and seeing its behaviour'. Or alternatively, if we have a long series of observations, say, over time, on all the variables, we may construct a regression formula using the earlier figures, and examine, in the rest of the series, the difference between observed values of the criterion variable and the predicted values from the regression function. When the agreement is good in some sense, a single formula may be worked out from the whole series. If not, we may have to look for other variables which may be changing over time and affecting the series of figures and whose inclusion might improve prediction. Such an analysis, which the meteorologists in India successfully used in examining the performance of the prediction formulae, serves the additional purpose of convincing the applied worker of the validity of the technique. It is worth undertaking it specially in situations where the observations are taken in sets over time or space or in accordance with some other factor.

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[7] This is the average value of stature of the father, and the transmuted stature of the mother. Galton obtained the transmuted values (or the male equivalent) by multiplying the female measurements by the factor 13/12.

[8] The conclusions are the consequences of the regression co-efficient of son's height on father's being less than unity.

Application in sample surveys (*Double sampling*) : An important use of multiple regression is in sample surveys where the object is the estimation of an average of a characteristic y in a population, by sampling for a number of related and easily ascertainable characteristics $x_1, x_2, \ldots$. When the regression of y on the related characteristics is unknown, a relatively small sample may be examined for all the characteristics to estimate the regression function. If $y = a+b_1x_1+b_2x_2+\ldots$ is the true or estimated (on the basis of a preliminary sample) regression equation and $t_1, t_2, \ldots$ are the estimated mean values of $x_1, x_2, \ldots$ based on a larger survey using any design, then the estimate of the mean of y is $a+b_1t_1+b_2t_2+\ldots$. Mahalanobis (1941) used this technique in forecasting the yield of cinchona bark by taking concomitant measurements on standing trees, such as their height, girth and thickness of the trunk at specified heights.

Estimation from fragmentary data : Rao and Shaw (1948) used the regression of cranial capacity on length, height and breadth of skulls to show that smaller skulls have a greater chance than bigger skulls of being recovered intact in excavations of old burial grounds for skeletal material. This suggests that the average cranial capacity of well preserved skulls underestimates to some extent the mean value for the skeletal population as a whole. Concomitant measurements such as length, height and breadth which could be taken even on broken skulls would provide, by the regression technique, a more representative estimate of the mean cranial capacity.

Selection problems (*single stage, single and differential predictors*) : There is a group of problems such as industrial selection (recruitment for different jobs), admission of students to universities and institutions for higher education, vocational guidance, psychiatric screening of military recruits, selection of high yielding plants, etc., where the regression technique enables the choice of a given quota of individuals with the maximum expected 'pay-off' which is the criterion variable expressed in money terms. A very general formulation of these problems is as follows.

Let $\boldsymbol{x} = (x_1, x_2, \ldots, x_p)$ represent the p.v.'s and $y_1, y_2, \ldots, y_s$ the pay-offs corresponding to s criterion variables. The regression of y_i on $\boldsymbol{x}$ is denoted by $\mathrm{R}_i(\boldsymbol{x})$. Let us find a region w in the space of $\boldsymbol{x}$ such that

$$\int_w dF(\boldsymbol{x}) = \alpha \,(\text{given}) \qquad \ldots \quad (3.1)$$

$$\int_{w\times y_i} y_i \, dF(y_i, \boldsymbol{x}) = \int_w R_i(\boldsymbol{x}) \, dF(\boldsymbol{x}) \geqslant c_i \text{ (given)} \quad \dots \quad (3.2)$$

$$i = 2, \dots, k \leqslant s$$

and

$$\int_w R_1(\boldsymbol{x}) \, dF(\boldsymbol{x}) \text{ is a maximum.} \quad \dots \quad (3.3)$$

By an application of the Neyman-Pearson lemma, we find that w is of the form

$$R_1(\boldsymbol{x}) \geqslant a_2 R_2(\boldsymbol{x}) + \dots + a_k R_k(\boldsymbol{x}) \quad \dots \quad (3.4)$$

in which case the equations (3.1, 3.2, 3.3) reduce to, say,

$$\left.\begin{array}{l} g_0(a_0, a_2, \dots, a_k) = \alpha \\ g_i(a_0, a_2, \dots, a_k) \geqslant c_i, \; i = 2, \dots, k \\ g_1(a_0, a_2, \dots, a_k) \text{ is a maximum.} \end{array}\right\} \quad \dots \quad (3.5)$$

The determination of $a_0, a_2, \dots, a_k$ is then a programming problem generally non-linear in nature. If, however, the inequalities in (3.2) are replaced by equalities then the coefficients $a_0, a_2, \dots, a_k$ are determined from the equations

$$\left.\begin{array}{l} g_0(a_0, a_2, \dots, a_k) = \alpha \\ g_i(a_0, a_2, \dots, a_k) = c_i, \; i = 2, \dots, k. \end{array}\right\} \quad \dots \quad (3.6)$$

We thus have a formal solution to the problem of selecting on the basis of p.v.'s a given quota of individuals in the long run, so as to maximise the expected payoff with respect to a certain characteristic, subject to the condition that the expected payoffs for certain other characteristics are not less than preassigned values. If there are no restrictions such as (3.2) the selection rule reduces to (Cochran, 1951; Roy and Mitra, 1954)

$$R_1(\boldsymbol{x}) \geqslant a_0.$$

An alternative problem is that of selecting individuals for different criteria, in given proportions, so as to maximise the total payoff. Let $\alpha_1, \alpha_2, \dots$ be the proportions for various criteria. The problem is to find regions $w_1, w_2, \dots$ so as to maximise

$$\int_{w_1} R_1(\boldsymbol{x}) \, dF(\boldsymbol{x}) + \int_{w_2} R_2(\boldsymbol{x}) \, dF(\boldsymbol{x}) + \dots$$

subject to the conditions

$$\int_{w_1} dF(\boldsymbol{x}) = \alpha_1, \; \int_{w_2} dF(\boldsymbol{x}) = \alpha_2, \dots \quad \dots \quad (3.7)$$

Using a generalisation of Neyman-Pearson lemma (Rao, 1948a, 1951a) the regions are found to be

$$w_i : \ R_i(x)+\lambda_i \geqslant R_j(x)+\lambda_j, \quad j = 1, 2, \ldots \qquad \ldots \quad (3.8)$$

where $\lambda_1, \lambda_2, \ldots$ are determined to satisfy the equations (3.7).

The solutions (3.4) and (3.8) are valid only in the long run. In practice one has to select from a given number N of applicants, on whom values of the p.v.'s can be ascertained. Denoting by R_{ij} the expected value of the i-th c.v. given the p.v.'s of the j-th individual we consider the payoff matrix :

Individual no.	Expected payoff for the criterion variables		
1	R_{11}	R_{21}	$\ldots R_{s1}$
.			
.	.	.	$\ldots$
.			
N	R_{1N}	R_{2N}	$\ldots R_{sN}$

If n individuals are to be chosen to maximise the sum of $R_{1\lambda}$ subject to the condition that the sums of $R_{2\lambda}, \ldots, R_{k\lambda}$ are not less than preassigned values, the selection rule is to choose the i-th individual if and only if

$$R_{1i} \geqslant a_0 + a_2 R_{2i} + \ldots + a_k R_{ki} \qquad \ldots \quad (3.9)$$

where $a_0, a_2, \ldots, a_k$ are chosen to satisfy the stated restrictions on the sums, which is a problem of linear programming. It may be possible that no solution exists in which case the conditions have to be altered so as to make them consistent (yield a solution for $a_0, a_2, \ldots, a_k$), or the constants as determined by equations (3.4) in the 'long run case' may be used, choosing $\alpha = n/N$.

If the problem is one of differential prediction (Brogden, 1951) i.e., of dividing N applicants into s groups of $n_1, n_2, \ldots, n_s$ individuals for the s criteria, then the i-th individual is assigned to the j-th criterion if and only if

$$R_{ji} + \lambda_j \geq R_{qi} + \lambda_q, \ q = 1, \ldots, s. \qquad \ldots \quad (3.10)$$

where λ_j are chosen such that the procedure (3.10) leads to given numbers of individuals for the various criteria. This is again a particular case of linear programming; however, a simple geometrical solution exists in the case of three groups (Rao, 1952, p. 328).

One important problem to be considered is the estimation and test of significance of selective efficiency[9] of the p.v.'s for a criterion variable y_1

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[9] selective efficiency of a procedure is defined as the increase in the mean value of the selected group over that in the case of random selection.

when some restrictions are placed on the expected values of other c.v.'s in the selected group. This problem has been recently solved by the author and the results are being published.

Sequential (multistage) selection procedures : All the p.v.'s may not be available in a single stage, at a given point of time, to decide on the selections. It may be convenient then to adopt a sequential method. At each stage when a fresh set of p.v.'s is available we may, in any individual case, select, reject or postpone decision till further observations are obtained. At the last stage when no more p.v.'s are intended to be observed there are only two possible decisions, viz., selection or rejection. Such a sequential procedure of selection results in considerable economy as the cost of obtaining information on the p.v.'s at subsequent stages is confined only to those provisionally selected at the previous stage.

To specify a sequential procedure we may use certain quotas of selection and rejection at each stage. We shall consider the simple, but important case of two-stage selection, where, in the first stage a given proportion of individuals is provisionally accepted and from among those provisionally accepted another given proportion is selected at the second stage, by using further information.

Let us denote the first stage p.v.'s by $\boldsymbol{x} = (x_1, x_2 \ldots)$ and the second stage, by $\boldsymbol{u} = (u_1, u_2, \ldots)$. The proportion to be selected in the first stage is β and both stages together is α. If w_1 denotes a region in the $\boldsymbol{x}$ space for first stage selection, w_2 a region in the product space of w_1 and $\boldsymbol{u}$ for the second stage selection, and $R(\boldsymbol{x}, \boldsymbol{u})$ is the regression of the criterion variable on $\boldsymbol{x}$ and $\boldsymbol{u}$, then the problem is to maximise

$$\int_{w_2} R(\boldsymbol{x}, \boldsymbol{u})\; dF(\boldsymbol{x}, \boldsymbol{u}) \qquad \ldots \quad (3.11)$$

subject to the conditions

$$\int_{w_1} dF(\boldsymbol{x}) = \beta \text{ and } \int_{w_2} dF(\boldsymbol{x}, \boldsymbol{u}) = \alpha$$

It is easy to see that w_2 is defined by $R(\boldsymbol{x}, \boldsymbol{u}) \geqq \lambda$ where $\boldsymbol{x} \in w_1$, so that if w_1 is given, w_2 is completely specified. For given λ let

$$\int_{w_2} R(\boldsymbol{x}, \boldsymbol{u}) dF(\boldsymbol{x}, \boldsymbol{u}) = \int_{w_1} f_0(\boldsymbol{x}, \lambda)\; dF(\boldsymbol{x}) \qquad \ldots \quad (3.12)$$

$$\int_{w_2} dF(\boldsymbol{x}, \boldsymbol{u}) = \int_{w_1} f_1(\boldsymbol{x}, \lambda)\; dF(\boldsymbol{x}) = \alpha, \quad \int_{w_1} dF(\boldsymbol{x}) = \beta \qquad \ldots \quad (3.13)$$

Then the best choices of w_1, w_2 for given λ are

$$\left.\begin{aligned} w_1 &: \; f_0(\boldsymbol{x}, \lambda) \geqq a_1 f_1(\boldsymbol{x}, \lambda) + a_0 \\ w_2 &: \; R(\boldsymbol{x}, \boldsymbol{u}) \geqq \lambda \end{aligned}\right\} \qquad \ldots \quad (3.14)$$

where a_1 and a_0 are determined to satisfy the equalities (3.13). We can then choose λ to maximise (3.12). The actual solution is thus extremely complicated although some simplification is possible when the variables have a multivariate normal distribution. Cochran (1951) suggested the regions

$$w_1 : R(\boldsymbol{x}) \geqq \mu, \quad w_2 : R(\boldsymbol{x}, \boldsymbol{u}) \geq \lambda$$

which, no doubt, lead to a simple procedure of selection, but differ considerably from the optimum solution (3.14) as may be expected.

As in earlier problems, if to begin with there are N individuals providing information on the first set of p.v.'s, n_1 are to be provisionally accepted at the first stage and n_{12} are to be ultimately selected, the solution is the same as in (3.14), except that the constants are determined such that the procedure selects only the specified numbers of individuals, n_1 and n_{12} at the two stages.

Formal solutions may be obtained for other sequential procedures, but the computations needed would be extremely heavy.

Prediction in a stationary series : In the examples considered earlier a qualitative distinction could be made between the p.v.'s and c.v. in that they represented the measurements of different characteristics. But this need not be so as when we would like to predict the price of rice next month on the basis of the prices in the previous months, or the height of the next individual to be drawn from a group given previously observed heights of a number of individuals drawn at random from the same group, or the number of defectives in a sample of a given size from the next lot of articles supplied for inspection on the basis of knowledge available from the previous lots. In all such cases the p.v.'s are what have been observed in the past and the c.v. a future observation on the same characteristic. The problem is, in general, that of estimating the distribution function of future observations, or simply some characteristic of the distribution such as the mean, or approximations of given functional types to the mean etc. Satisfactory solutions are available by the method of Fiducial Probability (Fisher, 1956), in situations where the conditions for its application are satisfied as in the problem of predicting the height of the next individual to be drawn, or the number of defectives in a sample from a given lot. In other cases large sample methods are available.

An important application is prediction in a time series which constantly arises in economic, scientific and technological investigations such as the prediction of future prices, meteorological forecasts, random noise in communication theory, turbulence, storm-generated ocean waves etc. There is considerable literature on the subject originating with the works of Kolmogoroff (1941) and Wold (1938). The problem is one of fitting a linear regression function of x_h, the variable after time h, on a large (theoretically infinite) number of previous variables x_{-1}, x_{-2}.... Traditional methods are not applicable as the inversion of an infinitely large covariance matrix is involved. It is, however, possible to obtain a prediction formula involving an infinite number of previous variables, which could be used as an approximation when a large series is available, under some conditions on the underlying stochastic process. One main condition is stationarity or weak stationarity which specifies that the covariance between x_r and x_s is a function of the difference $(r-s)$ only. For other conditions and detailed computations reference may be made to the book on stochastic processes by Doob (1952). Recently Wiener and Masani (1958) generalised the results to multivariate stochastic processes. In particular they considered the simultaneous prediction of the variable at a number of future time points.

4: DISCRIMINANT FUNCTION AND DISCRIMINATORY TOPOLOGY (C.V'S ON NOMINAL AND P.V.'S ON INTERVAL SCALE)

The theory of the discriminant function arose out of a procedure suggested by R.A. Fisher for sorting a collection of jaw bones according to sex of the owner. The problem is one of predicting sex (male or female) of the owner in each case from a number of measurements on the jaw bone. In such a situation, the criterion variable, viz., sex, has only a nominal scale while the predictor variables may have an interval scale.

The formal mathematical solution was supplied by Welch (1939) in the case of classification of an individual into one of two alternative populations. Let $\boldsymbol{x} = (x_1, x_2, \ldots)$ denote the p.v.'s and $f_1(\boldsymbol{x}), f_2(\boldsymbol{x})$ the probability densities for $\boldsymbol{x}$ in the two populations, and π_1, π_2 the relative frequencies of individuals of the two populations. By applying Bayes' theorem on conditional probabilities we find that the *a posteriori* probabilities for an individual with measurements $\boldsymbol{x}$ to belong to the first and second populations are proportional to $\pi_1 f_1(\boldsymbol{x})$ and $\pi_2 f_2(\boldsymbol{x})$ respectively. To minimise the errors of classification the Bayes solution is to assign the individual to the first population if

$$\pi_1 f_1(\boldsymbol{x}) > \pi_2 f_2(\boldsymbol{x}), \qquad \ldots \quad (4.1)$$

and to the second population if

$$\pi_2 f_2(\boldsymbol{x}) > \pi_1 f_1(\boldsymbol{x}), \qquad \ldots \quad (4.2)$$

and any random assignment may be followed in the case of equality.

We can consider, if necessary, the losses involved in wrong decisions and minimise the expected loss. If r_{ij} stands for the monetary return in classifying an individual of the i-th population to the j-th population, then the regression of the payoff (or monetary gain) when an individual with measurements $\boldsymbol{x}$ is classified as a member of the first population is proportional to (using *a posteriori* probabilities)

$$r_{11}\pi_1 f_1(\boldsymbol{x})+r_{21}\pi_2 f_2(\boldsymbol{x}) \qquad \ldots \quad (4.3)$$

and for the second it is proportional to

$$r_{12}\pi_1 f_1(\boldsymbol{x})+r_{22}\pi_2 f_2(\boldsymbol{x}). \qquad \ldots \quad (4.4)$$

Following the concept of differential predictors of Section 3 (multiple regression), where an individual is selected for a job where his expected payoff is a maximum, the individual is assigned to the first population if (4.3) $>$ (4.4) and otherwise to the second.[10]

The extension of this solution to classification of an individual as a member of one of several alternative populations is again a simple application of Bayes' theorem and regression function ; explicit solutions are given in (Rao, 1948a, 1950, 1951a, 1951b, 1952).

Although the formal solutions are simple there are a number of practical difficulties in their application. We shall consider a few examples and examine how the problems are solved in practice.

Differential diagnosis of neurotic states : Diagnosis of different types of neurotic diseases such as Anxiety state, Hysteria, Psychopathy, Obsession, Personality change and absence of any abnormality is extremely complicated in practice. Any mechanisation at least in distinguishing between states not close to one another in mental deterioration will be useful. A number of psychological tests administered to patients, previously classified into these states, showed differences in the response patterns and threw out the possibility of using an individual's response pattern in differential diagnosis. Using the estimates of their mean values, and variances and covariances the probability density of the test scores, say, $x_1, x_2, \ldots,$ for any neurotic group or a normal group can be computed. The relative frequencies of these patients and normal individuals coming for diagnosis will also be available from past experience. We thus have all the pre-requisites for an application of the discriminant function. Rao and Slater (1949) showed that a routine application of the method involves the computation of a linear discriminant score on an individual for each of the possible categories and assigning him to the category with the highest discriminant score.

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[10] The solution (4.1, 4.2) refers to the special case where the payoff for correct classification is 1 and for wrong classification zero. In the general case the problem is essentially an application of multiple regression and differential prediction.

There are other clinical applications such as the discrimination between two types of Jaundice, one of which needs a medical treatment and the other surgery. It has been found that two biochemical tests carried out with very little expense provide a discriminant function for classifying the patients into one of the two groups. The discriminant function can thus provide an objective criterion for coming to decisions. It is not suggested that other observations of diagnostic value should not be taken. It is only claimed that in routine work where the resources enable only a limited number of tests to be carried out on an individual there exists an optimum procedure which minimises the errors of misclassification or the overall risk if magnitudes of risk due to different types of wrong classification are specified.

Differential diagnosis, Doubtful region : The procedure outlined above no doubt reduces the probability of mis-classification to the minimum possible, but if this is large we do not have sufficient assurance in individual cases. However, whatever may be the measurements available, it should be possible in some cases to come to a decision, subject to a small pre-assigned risk, whereas in other cases either no decision or only a provisional dicision could be made. The latter comprises the doubtful cases which need further examination. The rules for such decisions can be formulated on the basis of the likelihood ratio as in the earlier problem. Details of such sequential procedures are given in (Rao, 1952).

Classification of Fossils : In problems of discrimination such as sexing of skeletal remains or the diagnosis of type of Jaundice, the possibilities of identification are generally limited to two. However, where the external evidence is slight or equivocal, the assignment of an individual to one of two groups may be subject to another type of error, viz., the wrong assumption that he belongs to one of the two groups when, in fact, he comes from a third unknown group. In the absence af any definite knowledge, we may have to provide for the possibility of not accepting the individual for either of the given groups.

Consider, for example, *Australopithecus africanus*, a fossil (consisting of the face, part of the base of the skull, the jaws and teeth) discovered in Africa and described in a letter to Nature by Dart (1925). There is considerable controversy (Dart, 1934; Ashton and Zuckerman, 1950; Bronowski and Long, 1951; Yates and Healy, 1951) whether *A. africanus* is more 'hominid' than 'anthropoid'. Comparisons are made, for this purpose, between the measurements of fossil teeth with those of men and the anthropoid apes. Bronowski and Long (1951) computed a linear discriminant function between chimpanzees and men on the basis of four measurements on teeth and found that *A. africanus* is not significantly different from men but significantly different from chimpanzees with respect to the discriminant function. They concluded that *A. africanus* is more hominid. The procedure followed is efficient only when it is known that the fossil belongs either to one of the two groups considered or corresponds to some species with mean values lying on a linear path (evolutionary?) connecting the mean values of men and chimpanzees. We may, therefore, approach the problem by first testing the latter hypothesis, which when not rejected by the data may justify the use of the discriminant function for coming to a decision. On the other hand, if this hypothesis is rejected, or if with respect to the discriminant function the measurement on the fossil is significantly different from the means of the two groups we have evidence that the discovered fossil possibly belongs to a third group.

If μ^1, μ^2 are the vectors of mean values for the given groups and Λ is the common dispersion matrix and $\boldsymbol{x}$ is the vector of measurements on the fossil, then the χ^2 on p degrees of freedom for testing the deviation of $\boldsymbol{x}$ from one of the groups with mean (say) μ^1 is

$$(\boldsymbol{x}-\mu^1)' \Lambda^{-1}(\boldsymbol{x}-\mu^1), \qquad \ldots \quad (4.5)$$

and this can be decomposed into two components

$$\frac{\{(\boldsymbol{x}-\mu^1)'\Lambda^{-1}(\mu^1-\mu^2)\}^2}{(\mu^1-\mu^2)'\Lambda^{-1}(\mu^1-\mu^2)}+\chi_2^2 \qquad \ldots \quad (4.6)$$

the first with 1 d.f. corresponding to the deviation with respect to the discriminant function and the other with $(p-1)$ d.f., to directions independent of the discriminant function. The second component χ_2^2 provides a valid test of the hypothesis that the discriminant function supplies all the information in coming to a decision. Using the computations given by Yates and Healy (1951) for the length and the breadth of tooth and adopting a reasonable value of $+0.3$ for the correlation coefficient between length and breadth[11], the value of χ_2^2 on $(p-1) = 1$ d.f. is of the order of 5, which is significant at the 5 percent level. This shows that (i) *A. africanus* perhaps belongs to a third species, a conclusion which the multivariate test leads to more definitely than the univariate approach[12] of Yates and Healy (1951) and (ii) the use of the discriminant function alone, by which Bronowski and Long (1951) concluded that *A. africanus* is not significantly different from men, can be misleading.

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[11] I have not been able to find out the value of the correlation coefficient used by Yates and Healy (1951). The conclusion is not altered even if the value is much smaller than $+0.3$.

[12] Yates and Healy found that the fossil is significantly different from chimpanzees in each of the two measurements and from men only in one of the measurements.

It may be noted that the χ^2 distribution we used in the problem of *A. africanus* is valid on the assumption that the mean values and the dispersion matrix of the two groups are well determined. The theory can, however, be applied even in small samples; the appropriate distributions in this case depend on the distribution of roots of certain determinantal equations. For the theoretical developments reference may be made to Fisher (1939), Hsu (1939) and Roy (1939). Associated problems and applications are contained in papers by Bartlett (1951), Rao and Slater (1949), Williams (1952) and others.

Vocational guidance : In which of the vocations $A, B, C, \ldots$, will an individual with given scores in a battery of tests have the maximum chance of being successful? Such a problem is sometimes considered as one of discrimination; i.e., of classifying an individual as a member of one of the vocation groups[13] A, B, C, ..., using the methods discussed above. But the logical situation in vocational guidance seems to be slightly different. Our attempt should be to compute for any individual with given test scores the chances of his being successful in each of a number of vocations. He could then choose a vocation in which his chance of success is a maximum.

Let $p_g(\boldsymbol{x})$ be the probability density of the test score $\boldsymbol{x}$ in the general population; $p_A(\boldsymbol{x})$ for those successful in vocation A; $p_B(\boldsymbol{x})$ for those successful in B and so on. If $s_i(x)$ is the probability of success in vocation i for an individual with test scores $\boldsymbol{x}$, then

$$p_i(\boldsymbol{x}) \propto p_g(\boldsymbol{x}) s_i(\boldsymbol{x}),\ i = A,\ B, \ldots \qquad \ldots \quad (4.7)$$

Hence $s_i(\boldsymbol{x}) \propto p_i(\boldsymbol{x})/p_g(\boldsymbol{x})$, the likelihood ratio of the i-th vocation to the general population, so that if a number of individuals have to be ordered by the probability of success in vocation i we can use $s_i(\boldsymbol{x})$ or $p_i(\boldsymbol{x})$ itself as an index.

To compare $s_i(\boldsymbol{x})$ over the vocations we need to know the constant of proportionality of $s_i(\boldsymbol{x})$ to the ratio $p_i(\boldsymbol{x})/p_g(\boldsymbol{x})$. If π_i is the ratio of those successful to the total number of persons in vocation i then

$$s_i(\boldsymbol{x}) = \pi_i p_i(\boldsymbol{x})/p_g(\boldsymbol{x}) \qquad \ldots \quad (4.8)$$

If π_i are known, then the chances of success over the vocations are proportional to $\pi_i p_i(\boldsymbol{x})$, which resemble discriminant scores in the discriminatory analysis with π_i representing *a priori* probabilities of the various groups. The vocation with the highest chance of success is that for which $\pi_i p_i(x)$ is a maximum.

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[13] A vocation group is the group of individuals who are successful in a particular profession.

The equation (4.8) provides a satisfactory solution to the problem of vocational guidance if at least approximate values of π_i are ascertained. This approach differs in the concepts involved from those found in the literature on vocational guidance.

Mahalanobis' D^2 and discriminatory topology : While considering the problem of classification of an individual into one of two given groups a question was raised regarding the extent to which errors of misclassification could be reduced by increasing the number of measurements. When the measurements follow a normal distribution it can be shown (Rao, 1948a) that the minimum probability of misclassification using p characters is a decreasing function of Mahalanobis distance D_p^2, defined by

$$D_p^2 = \Sigma\ \Sigma\ \alpha^{ij}\ \delta_i \delta_j$$

where δ_i is the difference in the mean values of the i-th measurement for the two groups and (α^{ij}) is the matrix inverse to the dispersion matrix. The question posed can then be answered by determining the limit D_∞^2 of D_p^2 as $p \to \infty$. If $D_\infty^2 < \infty$, there is a non-zero[14] lower limit to probabilities of misclassification and therefore, not much gain results by indefinitely increasing the number of measurements.

It is, therefore, of great interest to examine models of multivariate distributions with infinitely many dimensions and having finite values of D_∞^2 between groups.

Let us imagine hypothetical variables, $\eta_1, \eta_2, \ldots$ all uncorrelated and with unit variance and which may be denumerably infinite in number. The variables may be thought of as the hypothetical effects of major genes or polygenic systems (Mather, 1949) in which case they may be called genotypic variables. An observed measurement x_i may be considered as consisting of two parts, one determined by linear combinations of the genotypic variables and another a random variable, representing the effect of the environment. Thus

$$x_i = \Sigma a_{ji} \eta_j + \epsilon_i$$

Theoretically the index i may belong to any set, denumerable or not, thus admitting variables defined even with respect to a continuous set of coordinates.

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[14] Whatever may be the distribution of the variables the probability of errors of classification $\to 0$ as $D_p^2 \to \infty$, but it cannot be said that the limit is non-zero when D_p^2 does not diverge except in the special case of normal distributions.

Let D_p^2 be the Mahalanobis' distance between two groups based on a subset p of measurements x_i. When the effect of the environment is the same for the two groups, it can be shown by extending the arguments used earlier by the author (Rao, 1954b) that

$$\lim_{p\to\infty} \left\{ \begin{array}{l} \text{supremum } D_p^2 \\ \text{(over sets of } p) \end{array} \right\} \leqslant \Sigma\delta_i^2$$

where δ_i is the difference in mean values of the genetic variable η_i. We thus have a sufficient condition for convergence of D^2, viz., $\Sigma\delta_i^2$, the genetic distance between the groups be finite, which is true when the number of genetic variables in which the two groups differ is finite or when the differences in genetic variables, except for a finite number, are negligibly small so as to make the infinite sum of squares finite.

The convergence of the genetic distance opens out the possibility of studying relationships among given sets of groups based on genetic similarity or divergence by examining only a few measurements. With a suitably chosen small number of measurements it is possible to obtain a good idea of the underlying genetic distance with respect to which a classification of the groups is sought.

This line of work regarding classification of groups, originally introduced by Mahalanobis, has been fruitfully pursued by the workers at the Indian Statistical Institute and elsewhere and the methods developed have been successfully applied in a wide variety of situations (Blackith, 1957; Karve and Dandekar, 1951; Mahalanobis, 1928, 1930, 1936; Mahalanobis, Majumdar and Rao, 1949; Majumdar and Rao, 1958; Mukherjee, Rao and Trevor, 1955; Nair, 1952). Further details of the results quoted here are given in a paper submitted to the International Statistical Conference to be held in Tokyo in May this year.

General remarks : It has been generally assumed, in the derivation of the methods for discrimination, that the population parameters are known or estimated from a fairly large sample. Some appropriate procedures when parameters are obtained from small samples have been given by the author (Rao, 1954a). A deeper probe into this problem is necessary. In a recent paper John (1959) has examined the errors of misclassification for certain procedures taking into account the errors in estimation of the parameters.

5. PREDICTION OF THE UNOBSERVABLE
(HYPOTHETICAL VARIABLES)

We consider here problems of regression when the c.v. has an interval scale but is not observable. For instance, when a bull or a plant is chosen for further propagation, the c.v. is the expected performance of the progeny, which indeed is not directly measurable. Or we may like to grade a number of individuals with respect to a certain aptitude for which no direct measurement is available but which is reflected in the performance of an individual in a battery of tests. In such cases we postulate the existence of some variables, though unobservable, and predict their values through a study of their dependence on the observable variables.

Discriminant function for genetic selection: When quantitative characters are involved, it is considerably difficult to select genetically desirable types in breeding work because heritable differences are to some extent masked by non-heritable or environmental variations. The problem then arises as to what is the best indicator of the genotypic value of any individual line. Let $(\psi_1, \psi_2, \ldots)$ be the genotypic values of certain characteristics (like the annual number of eggs laid, the size of the egg, etc., in the case of poultry) and $(x_1, x_2, \ldots)$ the observed values of these characteristics on an individual of a progeny; our object is to predict $(\psi_1, \psi_2, \ldots)$ for a line from the observations on a number k of individuals of the progeny. Assuming linear regression it can be shown that the prediction formula for ψ_i is of the form

$$\psi_i = \alpha_i + \beta_{1i}\bar{x}_1 + \ldots + \beta_{pi}\bar{x}_p = R_i(\bar{x}) \tag{5.1}$$

whre $\bar{x}_j$ denotes average over k individuals of the progeny for the j-th character. The computations involved in the estimation of α_i and the β coefficients are discussed in a paper by the author (1953), where it was pointed out that the estimates depend on the sample size k available for each line. To predict the genotypic values of different lines for purposes of comparison and selection it may be, therefore, necessary to use different sets of regression coefficients when the individuals observed for each line are not the same. This has not been explicitly mentioned in the literature including my earlier exposition of the subject (Rao, 1952). For instance, Panse (1946) and others used a single set of coefficients even in situations where the numbers of samples for the various progenies are different.

There are also a few points on the computational side which are worth stressing. Generally, what is needed is the prediction of a linear compound of $\psi_1, \psi_2, \ldots$ using weights according to their commercial value. If individual regressions $R_i(\bar{x})$, (equation 5.1) are computed in advance, then it is easy to see that the regression equation for the linear compound $(a_1\psi_1 + a_2\psi_2 + \ldots)$ is simply $(a_1R_1(\bar{x}) + a_2R_2(\bar{x}) + \ldots)$. Such a procedure, instead of directly estimating the regression of $(a_1\psi_1 + a_2\psi_2 + \ldots)$ on $\bar{x}_1, \bar{x}_2, \ldots$, has some flexibility in that it allows for an easy adjustment of the prediction function if it is desired to alter the commercial values, or to compute functions for different sets of commercial values.

Another advantage in obtaining $R_i(\bar{x})$ to begin with, which can be done without heavy computations, is in the adjustment needed in the selection index under some restrictions such as, that selection should not alter the expected values of certain other genotypic characteristics. Let us represent by $(a, \psi) = [a_1\psi_1 + a_2\psi_2 + \ldots]$ the linear compound we want to maximise, and by (b, ψ), (c, ψ),... the other linear compounds in which no change is desired. The solution to such a problem of selection under restrictions is derived in Section 3 by an application of the Neyman-Pearson lemma. It was shown that if $(a, R) = [a_1R_1(\bar{x}) + a_2R_2(\bar{x}) + \ldots]$ is the selection index for (a, ψ), then the selection index under given restrictions is

$$(a, R) - \lambda_1(b, R) - \lambda_2(c, R) + \ldots \qquad \ldots \quad (5.2)$$

where $\lambda_1, \lambda_2, \ldots$ are chosen such that the covariances of (5.2) with (b, R),, (c, R), ... are all zero. The equations for $\lambda_1, \lambda_2, \ldots$ are

$$\begin{aligned} \text{cov } [a, R), (b, R)] &= \lambda_1 \text{cov } [(b, R), (b, R)] + \lambda_2 \text{cov } [(b, R), (c, R)] + \ldots \\ \text{cov } [(a, R), (c, R)] &= \lambda_1 \text{cov } [(c, R), (b, R)] + \lambda_2 \text{cov } [(c, R), (c, R)] + \ldots \\ \ldots \qquad & \qquad \ldots \qquad\qquad \ldots \end{aligned}$$

The procedure outlined above appears to be somewhat simpler than the application of formulae given by Kempthorne and Nordskog (1959) in the problem of restricted selection indices.

General remarks : A straight selection function $(a_1\bar{x}_1 + a_2\bar{x}_2 + \ldots)$ for the linear compound $(a_1\psi_1 + a_2\psi_2 + \ldots)$ is sometimes recommended when the extra computations involved cannot be undertaken or when the estimates of genetic and environmental variances and covariances are not very reliable or when there is very little extra gain by using the best possible index. An important statistical tool needed in this connection is a test of the hypothesis that the straight selection function is the best index. An exact solution is supplied when the genetic covariance matrix has rank unity, and only an approximate solution in other cases (Rao, 1953). Further research is needed in the solution of this problem.

Another line of investigation which needs further research is the theory of familial correlations obtained by generalising the univariate of intra-class correlation to multiple measurements (Rao, 1945). The nature of the genotypic variables $(\psi_1, \psi_2, \ldots)$ and its association with the corresponding observable variables on the progeny $(x_1, x_2, \ldots)$ can be studied with the help of familial correlations.

Factor analysis : The statistical procedures discussed in the previous sections are concerned with the best utilization of any given set of measurements such as the scores in a battery of tests in predicting a criterion variable. Given several alternative batteries of tests it is, however, possible by appropriate statistical analysis to choose the set which is most efficient for prediction. But the construction of alternative batteries of tests or the procedure for improving a battery of tests is itself a problem which has to be faced in practice. It is claimed that factor analysis would be of some use in this direction. Whether factor analysis by itself would be a proper guide in such cases is, however, a debatable issue.

Further, it is said that for predicting a criterion variable, factor scores extracted from test scores may be used. This is clearly an inefficient procedure, for the test scores themselves would be better predictors.

In order to understand how exactly factor analysis may be useful let us examine the problem as formulated by the psychologists. If $x_1, \ldots, x_p$ represent the test scores on an individual then the model considered is

$$x_i = a_{i1} f_1 + \ldots + a_{ik} f_k + s_i + \epsilon_i \qquad \ldots \quad (5.3)$$
$$i = 1, \ldots, p$$

where $f_1, \ldots, f_k, s_i, \epsilon_i$ $(i = 1, \ldots, p)$ are all uncorrelated hypothetical variables, s_i representing a variable specific to x_i, ϵ_i a random error and $f_1, \ldots, f_k$, each of which has non-zero coefficients for at least two of the variables x_i, representing common factors. The coefficients a_{ij} are unknown. It is easy to see that the correlations among x_i are solely due to the common factors which, as they appear in model (5.3), are neither unique nor operationally defined. We can make any orthogonal transformation of the factors and get a structure similar to that of (5.3). The problem differs in this respect from that of discriminant function for genetic selection where the hypothetical variables are defined as expectations of certain observable random variables.

Making use of the theory of canonical correlations developed by Hotelling (1936), a procedure called canonical factor analysis (CFA) was given by author (Rao, 1955a) for estimating a basis of the *whole space* of the common factors with the minimum rank necessary to explain the intercorrelations apart from sampling errors. This enables the prediction of any element of the common factor space provided it is specified in terms of the basis of the space (also Lawley 1940, 1942).

If factor analysis is to be considered as a method of predicting a hypothetical common factor, it is applicable only in situations where (i) an external criterion is not defined, (ii) the criterion in which we are interested is an element of the common factor space and (iii) this element is somehow identified and suitably specified in terms of the basis characterising the common factor space. There is nothing to guide us in the statistical technique of factor analysis regarding (ii) and (iii); the considerations have to be extra-statistical.

6. MULTIVARIATE TESTS OF SIGNIFICANCE

The construction of a prediction formula in any given situation involves prior statistical analysis of past data involving tests of hypotheses concerning the relationship between the p.v.'s and c.v.'s and estimation of unknown parameters. Typical hypotheses to be examined are : (i) Whether a given set of p.v.'s provide information on the c.v., (ii) Whether addition of other variables to a given set of p.v.'s improves the prediction of the c.v.'s and, (iii) Is a specified relationship between the p.v.'s and c.v. true?

The theory of least squares for testing linear hypotheses can be used in the multiple regression situation. Most of the multivariate tests developed have special reference to problems considered under the category of discriminant functions. Research in this direction originated with Wishart's (1928) distribution of the estimated variances and covariances and Hotelling's T^2 test (1931) and canonical correlations (1936), some of which were generalized by Wilks (1932, 1946). Fisher (1939) broke new ground with the introduction of test statistics for examining the dimensionality of the configuration of mean vectors of a number of populations. Similar test criteria were developed by Roy (1939) for testing equality of variance-covariance matrices of two populations. Two important papers concerning non-null distributions are by Fisher (1928) on the multiple correlation coefficient and by Bose and Roy (1938) on Mahalanobis' D^2. Approximations to complicated distributions of some multivariate test criteria are given by Bartlett (1939a), Box (1949), Rao (1948b, 1951c), J. Roy (1951) and others.

The problem of testing improvement in prediction by the addition of more predictor variables was examined by Rao (1946, 1948b, 1949) generalising a test proposed by Fisher (1940) for a hypothetical discriminant function (also Bartlett, 1939b, 1947). For further contributions useful in the general study of problems considered in the present paper reference may be made to books by Anderson (1958), Kendall (1954) and Rao (1952). Applications of multivariate tests are also contained in other papers by the author (Rao, 1954*c*, 1955b, 1956, 1958).

Multivariate tests are sometimes criticised on the ground that they are designed to test only overall differences, which are difficult to interpret, whereas the main interest often would be in examining individual differences in a few specified cases. It is argued that since univariate methods are admirably suited to the latter purpose, there is no need to indulge in the luxury of more complicated techniques, or to carry out a test which can detect differences of any sort and provide a logical basis for interpreting the individual differences.

It is, however, a wrong attitude to take that data should be examined only for the specific purpose for which they are collected, or that data collected should be just sufficient to answer problems of immediate interest. This is surely detrimental to scientific progress. Only an elaborate analysis and more comprehensive data can insure the research worker against possible pitfalls in the interpretation of statistical tests and, what is more important, provide clues for further investigation. The history of science tells us that several new discoveries made on the basis of evidence supplied by observed data were not envisaged by the investigator at the time of data collection.

7. A FEW OTHER PROBLEMS FOR RESEARCH

Nominal c.v. and nominal p.v.'s : Consider the problem of discrimination of three types of beetles, E_{12} Stigma, E_{28} Punctata and E Implicata on the basis of absence or presence of spots in each of 7 well defined positions on the thorax and/or 14 positions on the wing. If the presence of a spot is scored as '1' and absence as '0' arbitrarily, the scores of an individual can be represented as a vector $(a_1, a_2, \ldots)$ where each a can take values 0 or 1 with the order representing the positions. If the theoretical frequencies of the 2^7 possible vectors $(a_1, a_2, \ldots)$, in the case of 7 positions, are known for each of the species and if the relative abundance of members of these species is specified, then the Bayes solution can be used for discrimination. A major difficulty in this problem is the estimation of the frequencies of the $2^7 = 128$ combinations for each of the species from a preliminary sample. Since the number of unknowns is very large, 128 in the present case, no reliable estimates can be found without making any assumptions. Bahadur (1956) and Lazarsfeld (1956) have suggested different types of approximations to the theoretical frequencies involving the estimation of a fewer parameters. To what extent these approximations are adequate in practical problems has yet to be examined.

Ordinal c.v. : Suppose it was possible to obtain the scores in a battery of tests together with a ranking in performance on a particular job of a number of individuals. How can this information be utilised to predict the ranks for a fresh batch of individuals knowing only the test scores? If the underlying c.v. and the predictor variables can be considered to have a multivariate normal distribution, then it may be possible to construct the regression function apart from a constant by first estimating the necessary unknown parameters from the given data. The expression for probability of the observations is extremely complicated and therefore the method of maximum likelihood may not be practicable. Other simpler methods may be explored. Another procedure is to quantify the ranks by substituting for the observed i-th percentile rank the corresponding theoretical normal deviate. With such quantities for the c.v. the multiple regression method may be applied. No reasonable solution seems to be available when nothing is known about the distribution of the underlying c.v.

A closely related problem is the estimation of the regression function when only the ranks of the predictor variables have been observed and the c.v. has been measured on an interval scale. Assuming a multivariate normal distribution for all the underlying variables it may be possible to obtain reasonable estimates of the regression parameters.

Another problem of interest is the estimation of structural relationships from observations subject to errors with specified or unspecified distributions. A closely related problem arises in the study of organic correlation and allometry, where a straight line is fitted to show the relationship between two or more variates. Contributions by Teissier (1948) and Kermack and Haldane (1950) have led to a proper understanding of the problem and the difficulties involved in statistical estimation and tests. Some applications to paleontological problems have also been suggested by Kermack and Haldane (1950).

Often observations are taken on individuals from mixed populations. How can they be used to recognise that the sampled population is possibly a mixture of several homogeneous groups and to estimate the parameters of each of the groups as well as the proportion each group is to the mixture? Karl Pearson solved the problem of estimation when the mixture is of two normal distributions with different means and variances. Poti (1948) and Rao (1948a) worked out the procedure for equal variances, in which case the solution depends on a root of a simple cubic instead of a nonic equation which arises in Karl Pearson's problem. There is need to develop statistical methods for estimation and tests of significance for mixtures of three or more populations and also of non-normal populations. The need is somewhat acute considering the fact that in most field investigations data collected refer to a heterogeneous population.

I am grateful to Professor J B S Haldane for pointing out some problems which are analogous to those under discussion and which cannot be directly solved by methods discussed in this paper. One problem is the estimation of the frequencies of different genotypes (for example, 4 classes of genotypes A A B B C C, A a B B C C, A a B b C C, A a B b C c) among the parents knowing the numbers of dominant (i.e. having at least one dominant gene for each factor) and recessive children in each family. Another type of problem which is more difficult arises when the parents fall into even as few as two classes but the frequencies of progeny in each must be estimated from the data, a typical example of which is the data given by Bridges and others on primary and secondary non-disjunction.

In an attempt to describe to you some statistical procedures under the title, 'An indispensable aid in applied research', I hope I have not disappointed those who are interested in applications, by over-emphasizing the imperfections of existing statistical tools or by reference to unsolved problems. I would perhaps be failing in my duty as president of this section if I did not indulge in self-criticism as well.

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SECTION OF PHYSICS

Presidential Address

PRESIDENT : DR. S. PARTHASARATHY

SOUND AND HEAT

At the outset I express my thanks to the authorities of the Science Congress Association for electing me President of the Physics Section for this session.

The important part played by Sound in human affairs has been recognised from the very earliest of times. The Vedas, describing the creation of the Universe, mention the all pervading existence of the sound 'OM' when the universe was born. The significance which this syllable acquired in Hindu scriptures, both philosophical and religious, reveals the importance which our ancestors laid on sound as a form of energy. Curiously enough, while other forms of energy like heat, light and motion, though well-known for centuries, had to undergo a tortuous course of development and theorising before their origin could be explained, in the field of sound the origin and uses were well-known even to the earliest men. The artistic and aesthetic aspects of sound, known as music, underwent a remarkable growth and development since the dawn of history as evidenced by the classical treatises on music available even today. The experimental side of sound was equally well-developed and man has shown remarkable initiative and enterprise in making high quality musical instruments whose acoustical performance baffles the scientists even today when instrumentation has reached a high degree of perfection !

In spite of these early beginnings, the experimental scientific study of sound leading to our present-day knowledge in the field seems to have started comparatively recently in the 16th century. Studies in this branch of physics have been directed towards the elucidation of the various branches of this subject dealing with the generation, propagation and reception of sound. However, there is one aspect of the study which has not received any attention so far, I mean the study of sound as a form of energy and its convertibility to an equivalence with other forms of energy.

When it is recognised that one of the objectives of physics is to discover the general laws that govern the universe and that one of the simplest forms of such laws is obtained when it expresses the invariance of certain physical quantities, the enquiry into the basic relationships between various physical characteristics forms a fertile field of investigation.

The principle of conservation of energy is one of the most fundamental concepts in physics. The idea grew gradually in course of time and was firmly established in the 19th century. The quantitative equivalence between mechanical work and heat was experimentally established by the celebrated work of Joule and of Meyer in about 1840, independently of each other, while a similar relationship was sought between heat and electricity after a further period of 50 years which culminated in the accurate work of Callendar and Barnes correlating heat energy with electrical energy. The existence of a similar quantitative relationship between sound and heat has now been established as a result of an extensive project of work on the absorption of sound waves in liquid media carried out at the National Physical Laboratory of India in recent years.

The propagation of plane sonic waves in a medium is accompanied by a gradual attenuation of intensity due to absorption. For the study of this phenomenon liquids are the most suitable media. Sound waves travelling in a medium of acoustic impedance $\rho_1 u_1$ in contact with a second medium of acoustic impedance $\rho_2 u_2$ get reflected according to the familiar laws of continuity holding good at the surface of separation. The reflection coefficient α_r is governed by the usual law, viz.,

$$\alpha_r = \left[\frac{\rho_2 u_2 \cos\theta_i - \rho_1 u_1 \cos\theta_t}{\rho_2 u_2 \cos\theta_i + \rho_1 u_1 \cos\theta_t} \right]^2 \quad \ldots \quad (1)$$

where the quantities θ_i, θ_t have their usual significance. In the case of sound waves travelling in liquid contained in a thin walled container they suffer a series of multiple reflections due to abrupt change in acoustic impedance at the boundaries till they are completely absorbed. However, the liquids for thermal study have to be chosen with care. In some cases there is dissociation of the chemical in question. In some non-reacting binary mixtures a chemical reaction is induced by action of sound waves. If the mixture is chemically reactive the rate of chemical reaction is influenced by these waves. In any case part of the sound energy is dissipated as heat and part utilised in bringing about chemical reaction. Only in chemically passive media the sound energy can be equated to the heat produced.

The experimental procedure for the establishment of the equivalence of sonic and thermal energies consisted of two parts. In one a quartz plate was allowed to oscillate, with adequate power at its resonant frequency in the experimental liquid contained in a double walled glass vessel of the Dewar type to minimise heat losses. The amount of heat generated over a known interval of time was determined carefully by calorimetric methods. As the container was of the double walled type with vacuum in between any sound incident on the side walls was reflected back into the liquid. Likewise, since the characteristic impedance of the liquid medium was very high compared to that of air, there was almost total reflection of the sound from the liquid-air boundary at the top of the experimental liquid column. The sound waves, therefore, could not leave the liquid and were completely absorbed by the liquid by a process of repeated multiple reflections from the boundaries and finally dissipated as heat in the liquid. From the measured rise in the temperature of the liquid and other known parameters one can calculate the quantity of heat produced per second in the liquid due to the absorption of ultra sound. Heat is also produced in the system due to the passage of an electric current through the quartz crystal. This heating, called the dielectric heating, was corrected for by substituting the quartz crystal by a glass plate of identical thickness, plated area and dielectric constant and repeating the experiment once again. From these experiments the net heat produced in the liquid due to ultra sound alone was found.

To determine the intensity of the ultra sound at the surface of the crystal used in the foregoing study a second experiment was performed. In this set up the quartz crystal was maintained in oscillation in an identical state. From a knowledge of the constants of the radiometric vane, by extrapolation of pressure of radiation, one can easily estimate the intensity of the ultra sound at the source. Since the radiating area of the crystal was known the amount of sound energy given out by the crystal is readily calculable. Experiments carried out with a large numbers of non-reactive and passive organic liquids showed the existence of a regular relationship between sound and heat energies.

The following table gives a few representative results of experiments carried out in the laboratory. The two quantities—sound energy and the corresponding amount of heat—were invariably connected by the relation :

$$I = J \, . \, H \qquad \ldots \quad (2)$$

where I was the sonic energy and H the heat energy.

It was found that this constant of proportionality J had the same value as the Joule's constant which relates the conversion of mechanical energy to heat energy, namely, 4.2×10^7 ergs/calorie.

Having established their equivalence, we can examine in retrospect some of the earlier work which has direct bearing on the topic in as much as it shows that the transformation can take place in either direction viz. from sound to heat and heat to sound. It is well-known that as examples of reverse processes in work and electrical energies, one is reminded of heat being put to work as in engines and heat producing electricity as in thermoelectricity though with reduced efficiency. This is to be expected as heat is the lowest form of energy. It may now be asked whether in a similar manner the production of sound by heat has been possible.

TABLE I

Liquid	Temp °C	$\alpha/\nu^2 \times 10^{+15}$ cm^{-1} sec^2	Velocity $\times 10^{-5}$ cm/sec.	$AI_0 \times 10^5$ ergs/sec.	$H \times 10^3$ Cal/Sec (For same A)	I_0/H or $J \times 10^{-7}$ ergs/cal.
m-Xylene	30	0.89	1.293	1.21	2.85	4.24
Pyridine	25	5.20	1.400	6.37	15.7	4.05
Iso amyl alcohol	23	2.30	1.241	3.25	8.04	4.04
Chlorobenzene	20	0.98	1.291	1.57	3.83	4.10
Iso Propyl alcohol	23	0.92	1.170	1.29	3.04	4.21
Toluene	23	1.15	1.320	3.31	7.65 7.72	4.32 4.28
Nitrobenzene	30	0.89	1.490	1.90	4.37	4.34
Nitrobenzene	30	0.91	1.490	1.10	2.74	4.01
n-Butyl alcohol	23	1.10	1.268	1.88	4.47	4.20
n-Butyl alcohol	23	1.14	1.268	1.93	4.84	4.00
Cyclohexanol	30	4.89	1.428	6.36	14.8	4.29
Cyclohexanol	30	4.92	1.428	13.57	31.5	4.28
,,	30	5.07	1.428	6.54	15.8	4.14
,,	30	5.19	1.428	17.28	41.2	4.19
,,	30	5.22	1.428	3.29	7.8	4.22
,,	30	4.98	1.428	5.08	11.8	4.30
,,	30	4.70	1.428	8.25	19.2	4.29
,,	30	5.12	1.428	5.31	12.8	4.15
					Mean	4.19

The acceptance of the idea in the last century that heat is a form of energy was an important forerunner in the subsequent development leading to the formulation of the principle of conservation of energy. The effect of imparting more heat to a system is now known to contribute to the translational or rotational energies of the molecule. If we confine our attention to crystals, we find that unlike liquids and gases, the individual atoms are arranged in a three dimensional lattice and are so rigidly coupled to each other that it is not possible to disturb any of these without disturbing the other. The heat motions of these atoms consist of translational and rotational oscillations about their equilibrium positions. The motions of the various atoms have a phase relationship which impart to them the character of sound waves. The effect of the presence of the elastic waves manifests itself in the phenomenon of light scattering.

The phenomenon of scattering of light in the atmosphere was studied by Lord Rayleigh while the phenomenon of opalescence at the critical state was examined by Einstein and Smolouchowski. In the former case the scattering was produced to a noticeable extent by molecules in the air, while in the latter case in addition, it was due to density fluctuations. However, in both cases, the neighbouring scattering elements were treated as independent of each other and the theory needed modification when applied to solid and liquid media. According to the theories advanced by Debye, and by Born and Karman these media are seats of elastic waves of high frequency due to natural thermal agitation.

Brillouin repeated Einstein's calculations starting from Maxwell's equations,

$$\frac{\epsilon}{c^2}\frac{\partial^2 E}{\partial t^2} = \Delta E - \text{grad. div } E \qquad \ldots \quad (3)$$

where E is the electric field, c the velocity of light and ϵ the dielectric constant of the medium. He at first retained the assumption that the secondary radiation was small and hence substituted.

$$E = E_0 + e \qquad \ldots \quad (4)$$

where E_0 would be the electric field of light wave as if ϵ did not vary with position and e is the perturbation field. He thus obtained the intensities of the two Brillouin components as proportional to the square of

$$\frac{\sin \pi l_1\theta\left(\frac{\theta}{2\lambda}+\frac{1}{\lambda^*}\right)\sin \pi l_3\left(\frac{\theta}{\lambda}+\frac{1}{\lambda^*}\right)}{\pi l_1\theta\left(\frac{\theta}{2\lambda}+\frac{1}{\lambda^*}\right)\ \pi l_3\left(\frac{\theta}{\lambda}+\frac{1}{\lambda^*}\right)}$$

where l_1 is the width and l_3 the height of the ultrasonic region. These components evidently existed in addition to the central components corresponding to E_0.

Further, the parallel layers with varying refractive indices move with the velocity of sound in either directions and this introduces a change in frequency due to Doppler effect. The changed frequencies of the secondary radiations are thus

$$\nu \pm \Delta\nu = \nu\left(1 + \frac{u}{c}\mu \sin\theta\right) \qquad \ldots \quad (5)$$

where μ is the refractive index of the liquid, $\Delta\nu$ the frequency shift, u the velocity of sound and c that of light.

In discussions on light scattering by liquids it has been observed that liquids like solids were the seats of two types of molecular vibrations about the equilibrium positions. Translational vibrations involving a shift of the centre of gravity give rise to standing waves. These fluctuations give rise to coherent reflections of monochromatic light with change in frequency in accordance with Brillouin theory.

It is, therefore, seen that the shift of the Brillouin components denotes the velocity of propagation of the elastic waves in the medium. But the treatment so far does not reveal the cause for the variation in their intensities.

I had occasion earlier to refer to the Doppler shift in the scattered light as a consequence of the hypersonic waves present in the liquid and the origin of the Brillouin components in the scattered light. It has further been shown that superposed on the changes of density arising from changes in pressure, an additional variation of density due to local variation of temperature should also exist in the medium. This variation gives rise to an additional density scattering. Since these fluctuations do not have the characteristics of wave motion this part of scattering does not undergo any frequency change, and constitutes the polarised part of the central component. Landau and Placzek have shown from thermodynamic considerations that the ratio of the intensity of the central component I_c to the total intensity of the two Brillouin components I_b is given by

$$\frac{I_c}{I_b} = \frac{C_p - C_v}{C_v} = \gamma - 1 \qquad \ldots \quad (6)$$

where C_p = specific heat at constant pressure, C_v = specific heat at constant volume and γ is the ratio C_p/C_v.

This formula would suggest a way of verifying the assumptions on which the theory is based. Since some data are available of I_c/I_b and since from other considerations γ can also be calculated, it offers a ready means of comparing the results. The following table gives the values.

There is one paper of Medhi coming from Prof. S. C. Sirkar's Laboratory at Calcutta which gives a more accurate value for water, the ratio being less than 0.10.

If one takes two liquids such as water and glycerine for which γ is almost unity, unlike in carbontetrachloride or benzene, one could expect from the above considerations, I_c/I_b to be the same. On the contrary, while the central component in water almost vanishes, glycerine shows the central one brightest with the outer components almost vanishing. It would, therefore, appear that γ is not the only determining factor for I_c/I_b.

The earlier idea for the intensity of the components being dependent on viscosity only, is again found to be inadequate, for it was assumed that the sole factor for the damping of sound waves was viscosity as given by Stokes-Kirchhoff formula. But again, liquids of comparable viscosity, like carbondisulphide, carbontetrachloride, benzene, alcohols etc. give different intensity patterns of Brillouin components.

TABLE II

	Liquids	$\frac{I_c}{I_b}$ (observed) Venkateswaran	Rank et al.	$(\gamma-1)$ from Parthasarathy & Guruswamy
1.	Carbontetrachloride	0.84	——	0.45
2.	Methyl Alcohol	0.29	——	0.21
3.	Ethyl Alcohol	0.39	0.15	0.20
4.	Ethyl Ether	0.45	——	0.36
5.	Cyclohexane	0.65	——	0.33
6.	Water	0.36	0.14	0.01
7.	Acetone	0.79	0.42	0.42
8.	Isobutyric Acid	0.79	——	0.32
9.	Benzene	0.97	——	0.45
10.	Tetraline	1.20	——	0.20

The central component in carbondisulphide, benzene carbontetrachloride is brighter than the outer ones, not in conformity with expected results.

With these observations in mind we may infer that, since damping of the elastic waves is the only factor which can account for such varying intensities, in the attenuation of elastic waves both viscosity and γ are operative and that neither alone will account for it. This ratio I_c/I_b is, therefore, a function of sound absorption and this fact can be readily seen from the following table :—

TABLE III

	Liquids	I_c/I_b	$\alpha/\nu^2 \times 10^{17}$ cm^{-1} Sec.^{2}
1.	Benzene	0,97	808
2.	Carbontetrachloride	0,84	586
3.	Acetone	0,79	37
4.	Isobutyric Acid	0,79	—
5.	Cyclohexane	0,65	458
6.	Ethyl Ether	0,45	—
7.	Ethyl Alcohol	0,39	54
8.	Water	0,36	31,2
9.	Methyl Alcohol	0,29	30
10.	Tetraline	1,20	—

It now remains for the theoretical physicists to work out the relation.

An independent confirmation of the idea that both viscosity and γ are operative in ultrasonic absorption in liquids, is obtained from an exhaustive investigation of the relationship between observed sound absorption and physical properties carried out by the author and his collaborator. It has been shown that relation can be put down in the form

$$\alpha/\nu^2 = \left[\frac{2/3}{5/3-\gamma}\right]^4 \left\{\frac{8\pi^2}{3u^3\rho}\left(\eta+\tfrac{3}{4}\frac{\gamma-1}{C_p}k\right)\right\}$$

where the second term on the right hand side is due to Stokes and Kirchhoff and the first term involving γ is the additional factor. The results are in fair agreement with observed data on absorption; the exceptions are esters and organic acids for which the absorption is frequency-dependent even in the range of 1 to 15 Mc.

Since γ and I_c/I_b are related by the relation given by Landau and Placzek, and are found to hold good in mobile and ordinary liquids as against viscous liquids, the above formula can be re-written thus :

$$\alpha/\nu^2 = \left[\frac{2/3}{2/3-I_c/I_b}\right]^4 \left\{\frac{8\pi}{3u^3\rho}\left(\eta+\frac{\gamma-1}{C_p}k\right)\right\}$$

The above formula can be utilised in cases where γ values are not available but the ratio I_c/I_b is made available by an easy experimental determination.

The findings conclusively establish the mutual convertibility of heat into sound and sound into heat and provide us also with means of calculating one from a knowledge of the other. This knowledge has been of great help not only in developing the new thermosonic techniques for acouscal investigations but has thrown much light on the mechanism of sound absorption by liquid media.

We shall now examine how the knowledge of exact convertibility of sound to heat may be used in the determination of the absorption coefficients of liquids.

Normally in a plane parallel beam the sound intensities at two points separated by a distance x are related by the expression

$$I_2 = I_1 e^{-2\alpha x} \qquad \ldots \quad (7)$$

where α is the amplitude absorption coefficient of the liquid; since the intensities are directly related to the heat produced we can substitute H for I in the above expression : thus

$$H_2 = H_1 e^{-2\alpha x} \qquad \ldots \quad (8)$$

Two methods of estimation of α have been developed which are known respectively as the nonstationary state and the steady state methods.

In the former method the intensity of the sound beam at various distances from the source is determined by completely absorbing it at that point in a long double walled colorimeter. The sound energy is converted into heat and produces a rise of temperature in the liquid which is proportional to the intensity of the sound beam entering the calorimeter. If H_1 and H_2 represent the amount of heats developed in the calorimeter in two positions, along the axis of the sound beams separated by a distance x then the absorption coefficient is given by the relation

$$\alpha/\nu^2 = \frac{\log_e t_1 - \log_e t_2}{2x \, . \, \nu^2} \qquad \ldots \quad (9)$$

where t_1 and t_2 are the temperature rise due to H_1 and H_2 respectively, other parameters remaining constant.

In actual experiments a vertical sound beam of defined aperture was produced in the experimental liquid by exciting an x-cut quartz crystal having a fundamental frequency of 5 Mcs/sec. A double walled glass calorimeter about 20 cm. long was filled with a very highly absorbing liquid—say benzene—to absorb the incident beam completely. The bottom of the calorimeter was a thin mica film which permitted the passage of the sound beam into the liquid and could stand its weight.

The calorimeter was suspended symmetrically above the quartz crystal and the rise in temperature for a given length of time due to the passage of sound was recorded for different positions of the calorimeter. The absorption coefficient can then be calculated from equation (9). A correction has to be applied to the calorimeter for conduction and radiation effects. The liquid below the calorimeter is generally heated to a temperature higher than that within it. This results in a flow of heat through the mica window into the calorimeter which must be subtracted from the total heat recorded. Also as the liquids both inside and outside the calorimeter are at a temperature higher than the room temperature a radiation correction is equally warranted.

This method is susceptible to the effects of the divergence of the sound beam. They are minimised by keeping the base of the calorimeter wider than the width of the sound beam such that the entire sound beam is trapped by the calorimeter above. This remedy is quite effective particularly at high frequencies where the divergence of the beam is negligible or small. The accuracy of the results is dependant upon the precision with which temperature could be measured and also on the proper alignment of the calorimeter along the sound beam. If a mercury in glass thermometer is used the results are reproducible within ±10%.

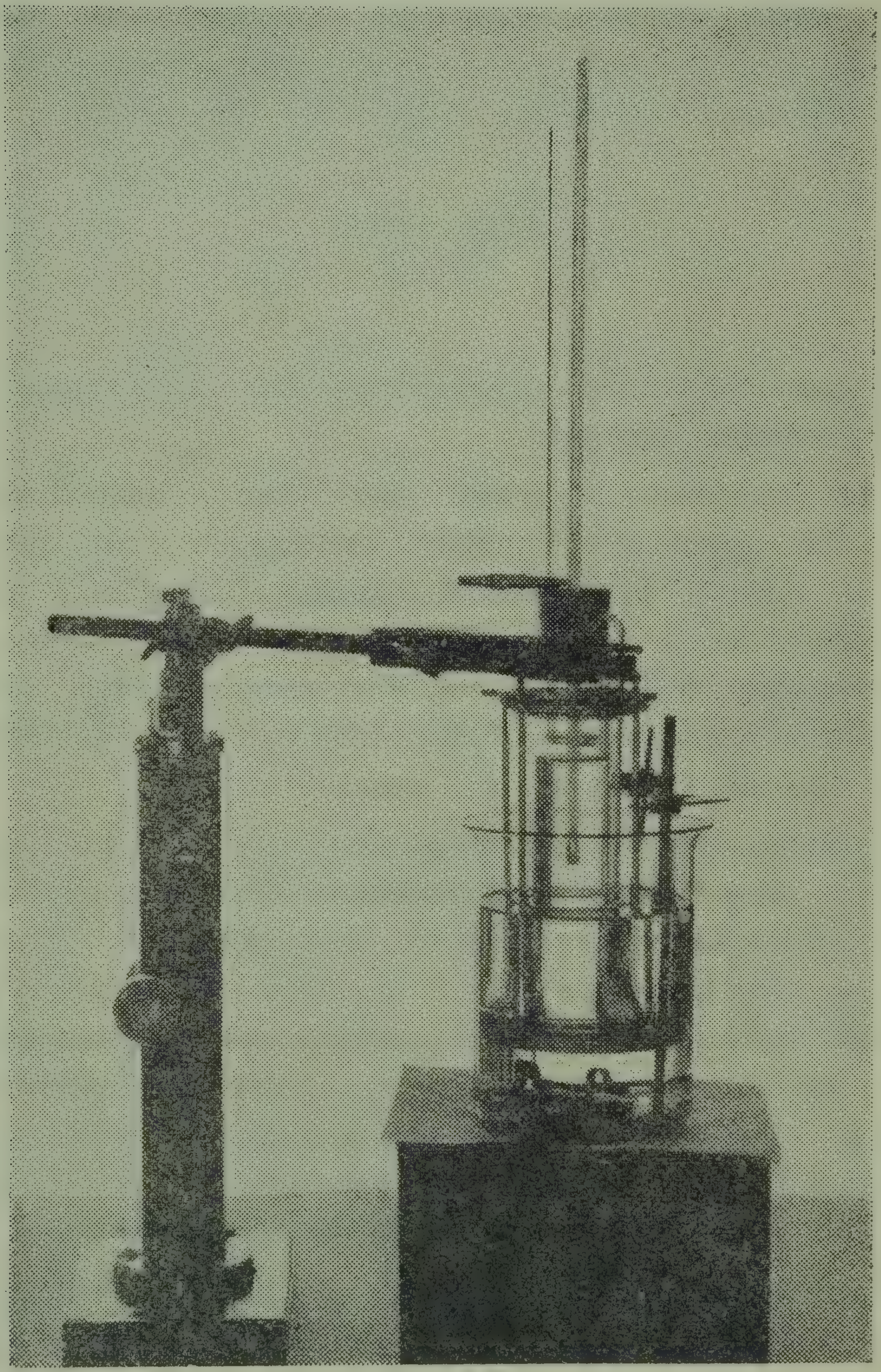

Fig. 1.

The values for the absorption coefficients obtained by this method compare favourably with those obtained by other methods in some well-studied liquids as shown in Table IV below.

TABLE IV

ABSORPTION COEFFICIENTS OF LIQUIDS

Liquids	Temp.°C	$\alpha/\nu^2 \times 10^{17}$ cm.$^{-1}$ sec.^{2} Thermal method	Radiation Pres.
1. Benzene	30.0	812	808 at 20°C
2. Carbon-tetrachloride	26.5	563	586 at 25°C
3. Xylene	25.5	116	89 at 30°C
4. Toluene	26.8	110	123 at 30°C

The thermal method has been used for determining the absorption coefficients of a large number of liquids. Grossetti, who has used this for sound investigations on water had obtained some results of great significance. Zienium has also used this method in his experimental work.

Another interesting method has also been developed for the estimation of absorption coefficients of liquids, by the author and his collaborators in the National Physical Laboratory of India. The method is based on the facts that the ultrasonic energy absorbed in short cells filled with the liquid is proportional to the path length of the sound beam in the cells. A small double-walled metallic cell with mica windows, filled with some liquid acts as a probe to measure the ultrasonic intensity at various distances from:the source. The sound energy absorbed by the liquid in the cell is converted into heat and raises its temperature till the rate at which the liquid loses heat to the surrounding liquid, maintained at constant temperature, equals the rate of heating due to absorption of sound energy. The temperature difference T thus set up between the liquids in the cell and in the bath is proportional to the ultrasonic intensity at the entrance to the cell and these two are related by the equation

$$I_0(1-e^{-2\alpha l}) = kT \qquad \dots \quad (10)$$

where l is the length of the cell, α the amplitude absorption coefficient, I_0 the intensity of the sound at the entrance to the cell, and k a constant of proportionality.

The absorption coefficient α/ν^2 in liquids can be estimated by intercepting the path of the ultrasonic beam produced in the experimental liquid by a small cell also filled with the same liquid at several points along the axis of the sound beam, the whole apparatus being kept in a constant temperature bath. If T_1 and T_2 be the difference in temperatures established in the steady state in two positions of the cell separated by a distance x the absorption coefficient is given by

$$\alpha/\nu^2 = \frac{\log_e T_1 - \log_e T_2}{2x \,.\, \nu^2} \qquad \ldots \quad (11)$$

If the temperatures are measured with a sensitive thermocouple arrangement we get

$$\alpha/\nu^2 = \frac{\log_e \theta_1 - \log_e \theta_2}{2x \,.\, \nu^2} \qquad \ldots \quad (12)$$

where θ_1 and θ_2 are the galvanometer deflections corresponding to temperature differences T_1 and T_2.

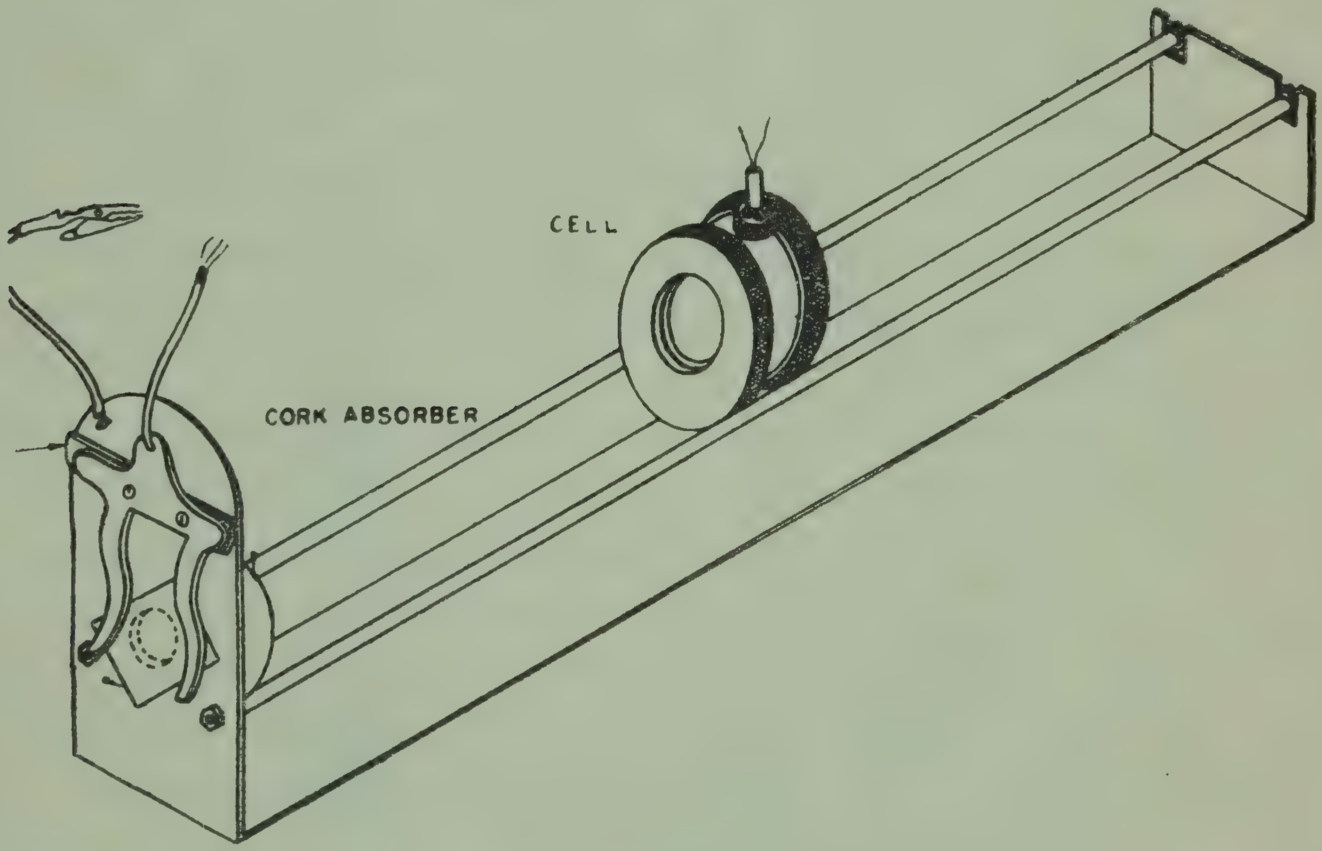

Fig. 2,

The movement of the cell along the axis of the beam was accurately guided with the help of a crystal holder-cum-track specially designed for this purpose (Fig. 2). The width of the beam was kept smaller than the aperture of the cell. Thus the effect of divergence was reduced in these experiments also. Reflections of sound beam from the far end of the liquid tank were avoided by using suitable foam glass absorbers.

This method has an advantage over the previous one in that the temperature differences here are measured by a more sensitive device and in a steady state so that they are more easily reproducible and reliable. The results obtained agree well with the results reported in the literature.

This method has been successfully employed to investigate several liquids. The values of α/ν^2 at 5 mcs. per sec. as obtained by this method for benzene, amyl acetate, and cyclohexanone among other liquids are 810×10^{-17}, 179×10^{-17}, 56×10^{-17}; cm^{-1} sec^2 respectively. The corresponding values by the radiation pressure method are 808×10^{-17} ; 166×10^{17} 59×10^{-17}, cm^{-1} $sec.^2$ respectively.

I shall now enumerate a set of experiments designed to apply thermosonic techniques for estimation of the transduction efficiency of a quartz crystal. This problem had not been tackled properly for the want of a suitable method to estimate the sound output accurately. Thermosonics offers a ready means of bridging the gap. The sound waves generated by the crystals oscillating in the liquid contained in the calorimeter suffer complete reflections from the bounding surfaces and the liquid-air boundary and thus get absorbed in the liquid giving out an equivalent amount of heat, of course, after making due allowance for the dielectric heating of the crystal. The ultrasonic energy input into the liquid can thus be calculated. The exact determination of the electrical input power has also been made to establish a quantitative relationship between the electrical power input and the ultrasonic power output.

Vigoureux has shown that the amplitude of oscillation of a quartz crystal in a liquid is directly proportional to the applied voltage across its surfaces. Whence it follows that the intensity of ultrasound emitted by the crystal is proportional to the square of the applied voltage. The experiments of Epstein, Anderson and Harden have shown that in the case of quartz one can obtain as much as 43 watts/sq. cm. before dielectric breakdown occurs. It was shown that as much as 65% of the total electrical power is converted into heat and the losses were attributed to mismatching in the electrical circuit.

The aim of the work was to determine in absolute measure the electrical power fed into the quartz crystal and its fraction converted into ultrasonic power. As the heating of the liquid is due to ultrasonic absorption and also due to dielectric heating, the later was found by a substitution experiment, in which a glass piece of identical dimensions and plated area as the quartz crystal was used. From these two sets of experiments one can find the total output as well as the ultrasonic output.

In one set of experiments using a crystal of frequency 4.916 Mc/sec in some twenty organic liquids some very interesting results were obtained. Defining total efficiency as the ratio of output thermal power to electrical input power one finds that in all the liquids studied the nature of the liquid plays an important part in determining the conversion efficiency total as well as ultrasonic—the ultrasonic efficiency being defined as the ratio of the ultrasonic output power to electrical input power. A comparison of the efficiencies total as well as ultrasonic with the several physical properties of liquids reveals that the percentage of energy converted into thermal energy is different in different liquids. Maximum total conversion takes place in liquids of low sound absorption and this efficiency decreases as the sound absorption increases. But the ultrasonic efficiency is low in low sound absorbing liquids and high in those with high sound absorption coefficient.

From further experiments at 2.84 M.C., 8.7 M.C. and 14.7M.C./sec. it is found that the dielectric heating is greater for liquids of low sound absorption and for liquids of very high sound absorption it is quite small. Great ultrasonic output is delivered in liquids of high sound absorption.

Experiments performed at several distinct frequencies varying the voltage on the crystal reveal that the total heat output varies directly as the square of the voltage applied to the crystal and on the frequency and the nature of the liquid in which it oscillates. Greater output is delivered in low sound absorbing liquids at low frequencies. When the dead capacity of the crystal is compensated for by an inductance the crystal with its liquid load behaves as a pure resistance.

It was also found that excitation of a quartz crystal at a higher harmonic is always accompanied by a lowering of the efficiency, i.e., in order to get maximum efficiency in a given liquid, at a given frequency, the crystal should oscillate at its fundamental.

Cady has shown that to maintain the amplitude of the given quartz transducer the same at hth harmonic as at its fundamental, the currents I_1 and I_h passing through it should be a relation

$$I_h = hI_1 \qquad \dots \quad (13)$$

Experiments performed at fundamental, third and fifth harmonics of a quartz crystal in several organic liquids prove that one does not get the rated output even if the condition as given in the above equation is maintained. Whereas the electrical input increases as the frequency increases, the output, total as well as ultrasonic, decreases (similar results were obtained earlier).

These results indicate that we can quantitatively estimate the electrlcal imput power as well as the total and ultrasonic power output from a quartz transducer by the methods enumerated in the previous paragraphs. There always remain a sizable percentage of the imput power which does not get converted into heat, the divergence increasing with increasing frequency. This aspect of the problem requires further elucidation.

On the basis of the work done in this direction on the efficiencies of a quartz crystal oscillating under various initial conditions an expression has been developed, which treats curves for efficiency and frequency in terms of certain parametric constants which have been calculated for the experiments under review, which shows that maximum ultrasonic efficiency may be obtained in high sound absorbing liquids at low frequencies.

Another interesting outcome of the subject of thermosonic is the study of the estimation of the amplitude of vibration of the transducer itself immersed in liquids, a subject which has defied thus far any experimental approach. Several methods based on optical interference, or changes in electrical constants have been suggested from time to time, but these are appliciable only to oscillations at low frequencies in air, and definitely unsuitable for crystals oscillating inside a liquid. In the method developed in the National Physical Laboratory the total sound energy radiated is estimated from thermal measurements taken over a known interval of time as outlined above. The sound power output P is given by the relation

$$P = 2\pi^2 \rho u . \xi^2 N^2 S \qquad \ldots \quad (14)$$

where ρ is the density, u the sound velocity, s the area of the radiating surface, N the frequency and ξ the amplitude of vibration. ξ is evaluated in terms of the value of P measured thermosonically, other constants being known.

Theoretically it is possible to estimate ξ from the relation

$$\xi = \frac{2c_{11} V d}{\pi u_1 \rho u} \qquad \ldots \quad (15$$

where c_{11} is the elastic modulus governing thickness vibrations of the quartz plate, d the piezo-electric constant V the applied voltage and u_1 the volocity of ultrasound in quartz, ρu being the characteristic impedance of the liquid in which the crystal oscillates. The amplitude works out to be of the order of 10^{-9} cm./volt of the exciting potential and varies from liquid to liquid. There is good agreement between the values of amplitude calculated theoretically and those obtained from thermosonic methods as shown in table V below:

TABLE V

AMPLITUDE VALUES OF QUARTZ PLATE IN LIQUIDS

Liquids	$\rho u \times 10^{-3}$	Amplitude $\times 10^{9}$ cm./volt (Thermosonic)	(Theoretical)
1. Toluene	115	1.15	1.69
2. Cyclohexanone	138	1.17	1.41
3. Chloroform	149	1.18	1.30
4. Ethylene-glycol	180	0.76	1.08

The experimentally obtained amplitude of the quartz plate is slightly less than the calculated one as it should be, and the agreement between them is within 20%.

The thermosonic methods outlined above may find useful application in another growing field in which ultrasonic waves are used for bringing about or influencing the rate of progress of a chemical reaction. These reactions include hydrolysis, esterification molecular rearrangement, conversion of geometric isomers etc. Many more reactions are envisaged.

For a systematic study of these problems a quantitative basis for the sound energy used in a chemical process is needed. It is expected that thermosonics will provide the means for this study.

An attempt has been made to enumerate briefly the experiments that culminated in the establishment of the equivalence of sonic and thermal energies. This in turn, has opened up a new branch of sonics very aptly termed 'Thermosonics', which helps considerably in the determination of physical quantities, many of which hithertofore have not been possible to measure experimentally. A relation between sonic and optical behaviour of liquids has also been found. One may confidently hope that this knowledge will pave the way for further elucidation of the behaviour of matter in the liquid state.

Before concluding I wish to acknowledge with warm appreciation the co-operation of the following members of the Division of Acoustics who have been associated with me in the above quoted work done at the National Physical Laboratory:

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SECTION OF CHEMISTRY

President :—PROF. ABANI K. BHATTACHARYA, D.SC., F.R.I.C. (LOND.)

PRESIDENTIAL ADDRESS

VELOCITY OF FLOW OF ORGANIC LIQUIDS THROUGH THE ADSORBENT COLUMNS AND THE STRUCTURE OF MOLECULES. THE EQUATION $\frac{vh}{t} \cdot \frac{\eta}{d} = K$

Science Congress is an annual function of the great lovers of science and its celebrities are marked by the great enthusiasm of the scientists of India and abroad who are interested in the progressive thoughts of science. It is, therefore, a great pleasure to be in your midst to deliver my humble address. While I discharge this duty, I feel deeply conscious of my indebtedness to you all for giving me this privileged opportunity of communicating my thoughts to this celebrated assembly of learned chemists. Congratulations from many of my friends weighed on me, indeed, but my heart all the same quailed in fear for the great responsibilities that lay ahead. The first obligation of this honour which you have bestowed upon me is to address the present gathering on a suitable topic, but I am conscious all the while of my limitations in presenting my views before this galaxy of eminent chemists whom I respectfully adore for their achievments in the realm of Chemistry. May I be pardoned for my limitations!

The topic which I propose to discuss is rather uncommon, yet I have reasons to believe that it will attract the attention of this learned gathering and provoke their thoughts on the problem. The flow of liquids through a porous medium, though considered to be a purely hydrodynamic problem, seems to be full of evidences which can be studied with a physico-chemical bias. It will be evidenced from the experimental facts that it is not only the dynamic factors but also the surface properties of the medium as well as the structure and functional groups of the molecules which play their part in conditioning the rate of flow of liquids through a porous medium.

I may now proceed to discuss these facts during the course of my humble address.

INTRODUCTION

The velocity of flow of liquids through a packed column is a particlar aspect of the flow of homogeneous fluids through a porous medium. In any column made of suitable adsorbents like silica, alumina, fuller's earth etc. there are a large number of voids which form the pores through which the liquids can flow or permeate with a certain velocity. These pores are arranged under packed condition in such a way as to form an interconnected network of channels which allow the liquids to form the stream of flow. The same is true for all porous bodies and the underground layers of the soil where the degree of compactness may vary from medium to medium according to the physical conditions of their formation. The engineers are frequently faced with specific problems of underground filters, petroleum beds, and water seepage, but they have their own limitations to solve such difficulties as involve the role of surface forces and structure of the liquid molecules. Mathematical equations, based on hydrodynamics, porosity and the geometrical shapes of the particles and passages, do not cover up all the factors which ultimately govern the velocity of flow of liquids through any porous column. Such limitations of purely mathematical or physical treatment of the phenomenon necessitate further study of the problem with a physico-chemical bias to elicit adequate information on the influence of the structures of the liquid molecules and also of the solid particles, when the liquids flow through the pores of a column. While the existing ideas regarding the capillary flow of liquids are mainly centred round the dynamic and porosity factors, the role of the physico-chemical forces operating in such systems does not seem to be less important. In order to bring out the evidences of the role of molecular structure on the velocity of flow of liquids through the porous columns the need of extensive investigations under controlled conditions of the height of the column, pressure, temperature, size and shape of the particles cannot be overemphasised.

SOME IMPORTANT REFERENCES TO THE THEORETICAL AND PRACTICAL INVESTIGATIONS OF THE PROBLEM

In a purely mathematical treatment fluids are considered as continuous media and the condition at any point is determined by the physically measurable quantities — density, pressure and temperature — which can be expressed by a functional relation. Besides these, there are the three components of velocity which are functions of the spatial co-ordinates (x, y, z) and time ' t '. The flow of liquids is based on the principle that the velocity distribution in every flow system requires a dynamic equilibrium between the inertial and viscous forces and between the external body forces and the internal distribution of the liquid pressures. The fundamental equations of motion, which are known as Navier-stokes equations, are highly non-linear, and hence there is no general method for solving them, unless some assumptions are made about the state of the fluid and a very simple configuration of the flow pattern is considered. This is why experimental investigations and model tests have been so strongly advocated by the mathematicians themselves in order to obtain adequate information on the behaviour of fluid substances and to resolve the insuperable complexities of a purely theoretical treatment.[13]

The earliest reference to the quantitative study of the rate of flow through a porous column is found in the classical work of Henry Darcy[5] in 1856 whereby he established that the rate of flow of water through a column of sand could be expressed by the equation $Q=K.A.\frac{h}{l}$, where l was the height of sand column or length of path, A was the area of the cross section, h was the drop in manometer height, and K was the proportionality factor called the permeability coefficient. This relationship soon became known as Darcy's Law and subsequently many attempts were made to give this simple empirical expression a more elaborate significance by including such other properties of the liquid as govern the velocity of flow through the porous columns. Slichter[14] in 1897, Smith and co-workers[15] in 1929, Grayton and Fraser[6] in 1935 made extensive studies on porosity and permeability under different modes of packing the columns with different size grades of particles. Slichter observed that permeability was proportional to the square of the radius, R, assuming that the particles were spherical. But Fancher, Lewis and Barnes[11] in 1933 investigated the same problem and observed that the proportionality between permeability and R^2 did not hold good in many cases. From these observations it was concluded that the particles were not spherical in all cases as had been assumed by Slichter and that the porosity, and shape of the pore spaces may be considerably affected by the size, shape and arrangement of the particles and these factors would ultimately change the permeability of the porous column.

The above conclusion seems to be only partially correct. In this connection results of a series of experiments published by Bhattacharya and Gupta[3] brought out a clear evidence of the fact that the velocity of flow not only depended upon the porosity and shape of the pore spaces due to the size and shape of the particles, but also on the characteristic surface forces of the material. In order to verify this fact, they graded the size of the particles between 60-80 mesh, 80-100 mesh and 100-120 mesh by successive sieving through the standard sieves. The striking feature of their observation was that, other conditions being kept equal, the rate of flow was slightly increased with the fineness of gradings. If porosity and pore spaces due to the size and shape of particles were the only factors, the velocity of flow of the same liquid should remain the same to the nearest approximation for columns of the same size gradings of different substances, like SiO_2, Al_2O_3 and MgO etc. But the observed rate of flow was different for columns prepared with different materials. The order of velocity, however, supported the fact that decrease in the size grades probably increased the porosity of the system which might have been responsible for the slight increase in the rate of flow. But since the velocity was different for different adsorbents, it was evidenced that porosity and surface characteristics both had their combined effect on the flow of liquids. Porosity is a measure of the fluid bearing capacity, while permeability is a measure of the ease with which the fluids may traverse the medium. Thus it can be visualised that the ease of flow may depend not only on the fluid capacity and the pressure, but also on how the surface properties react on the fluid and *vice-versa*. Such effects like swelling and hydration are the well known phenomena which affect the liquid carrying capacity ; hence it need not be too strongly emphasised that suitable modifications in the existing theory of flow are necessary to co-ordinate the dynamic factors with the surface forces and chemical structure of molecules. Due to the existence of such undefined forces the hydrodynamical equations do not give a satisfactory solution.

Slichter[14] formulated another equation for the quantitative study of the flow of ground water which was expressed as $10.22 \frac{Pd^2S}{\mu hk}$, where P was the difference of pressure, d, the mean diameter of the particles, S, the cross sectional area, h, the height of the column, μ, the coefficient of viscosity and k was a constant. In this equation Slichter recognised that the viscosity of the liquid is an important physical property to be considered along with the other variables in determining the flow of liquids.

In 1933 Zunker[12] brought in the formulation of his complicated equation a number of other factors such as (i) the number of free pore spaces, (ii) total number of pore spaces, (iii) the effective surface, and (iv) a factor for the arrangement of particles. In this formula, Zunker seems to be the first to recognise that the surface of the medium plays its effective role in the flow of liquids through a porous column, but it was difficult to verify his equation due to the lack of adequate techniques.

In 1942 Le Rosen[19] visualised that every solvent used in chromatography should have its flow characteristics which would depend upon the nature of the adsorbent column. On this assumption he made an ingenious approach to standardise the various adsorbents by evaluating a number of terms which were characteristic of the column and also of the solvents. The standardisation of the adsorbent column depended on the values of (i) the constant velocity of flow of the solvent, Vc, (ii) a number S for the average packing and (iii) the velocity of the movement of the adsorptive zone relative to that of the solvent expressed as R. These observations of Le Rosen in the technique of Chromatography are strongly suggestive of some kind of interaction between the solvent and surface forces in the column to give a constant velocity, Vc, characteristic of the adsorbent column. Such observations of Le Rosen lead to the corollary that, if the pressure, height of the column and size grade of the particles are fixed, the rate of flow will depend upon the structural characteristics of the liquid and of the surface.

SURFACE FILMS, STRUCTURAL AGGREGATES, SWELLING AND IONIC DIFFUSION

Hardy, Langmuir, Harkins and Adam's investigations on the spreading of liquids and formation of surface films furnished definite evidence of the orientation of long chain molecules due to polar interactions. The formation of uni- and multimolecular films at the contact surface of liquids was another interesting feature to support the existence of the forces of attraction at the interface. Harkins and Jura[7] in 1944 observed further that the films are also formed at the solid-liquid interface. Titanium dioxide-water interface is an interesting example where films of measurable thicknesses are formed. The thickness of such films was found to vary from liquid to liquid. They observed that at O°C the thickness of the film at the interface of titanium dioxide and butane was 64 Angstrom units, and it was suggested by them that the butane molecules lie flat on the surface. In some cases, characteristic aggregation or dispersion of solid particles also takes place in particular liquids. This has been observed in the behaviour of calcium carbonate when it is stirred in a polar or non polar liquid. In benzene, xylene, cyclo hexane, the particles of calcium carbonate form spongy clots, while in methyl and ethyl alcohol then become highly dispersed. Such properties of aggregation or dispersion in a particular liquid undoubtedly changes the structure of the medium. Hence the velocities of flow of benzene, toluene, xylene and cyclohexane were found to be greater than the alcohols, due to the specific types of the structural aggregates of the particles[3].

Swelling and shrinkage[2] is another remarkable property which we often come across in the behaviour of clays and some typical soils like the black cotton soil. Water logging in many areas is not an uncommon experience which arises from the low permeability and percolation. This kind of phenomenon is directly connected with soil structure and the properties of colloidal clay which are characterised by the surface forces of the system. The swelling phenomenon depends upon hydration of clay particles and on the common property of a large existing surface or potential surface and several other physico-chemical properties of the swelling solids as well as of the liquid. There are at least three characteristic types of swelling which are said to be due to three distinct processes (i) when polar liquids get bound up at the surface of a solid body thereby increasing its active volume, (ii) when non-polar liquids are associated with the solid body as a solid solution, and (iii) when polar liquids reacting with solids form a complex compound. The existence of these different kinds of swelling has been proved by X-ray spectrography.

The mechanism of swelling is based upon the fact that the solid swells by taking up a liquid without losing its apparent homogeneity when its volume is enlarged and its cohesion is diminished. There are forces acting at or within the surface of the porous material which attract the liquid within its pores with the result that it loses its free mobility. The non-polar liquids such as benzene and carbon tetrachloride do not cause any significant swelling, while the polar molecules of water fill the pores and suffer orientation on the surface of the particles to produce the phenomenon of swelling. Role of adsorbed ions is also important. For example, swelling of Putnam clay (beidellite) varies with the nature of the adsorbed cations in the following order, $Li > Na > Ca > Ba > H > K$, while the order of swelling for bentonite (montmorillonite) is: $Na > Li > K > Ca = Ba > H$. Lutz[12] observed that the lateritic colloids (halloysite) do not swell irrespective of the nature of the adsorbed ion in the exchange complex. The foregoing observations on the swelling of clays and other adsorbents lend a strong support to my view that the rate of flow through an adsorbent column is not only a function of the dynamic variables but also of the undefined surface forces, molecular orientation, and structure of liquid molecules.

Bigellow[4] (1907) and Bartell[1] (1911) reported some interesting observations on the diffusion of ions and neutral molecules through the semi-permeable membrane of copper ferrocyanide. They observed that the rate of diffusion of some salts was proportional to the adsorption of negative ions. Weiser[16] (1930) made an extensive study of the permeability of ions through the pores of copper ferro and ferricyanide membranes and observed that the chloride, sulphate and ferricyanide ions passed freely through the pores of these membranes but the ferrocyanide ions were held up in the pores. It was difficult to explain why some ions can diffuse readily, while some others are held up within the pores or diffuse very slowly. In order to explain such an anomalous behaviour of ions Weiser postulated that the diffusion of ions through the pores of the membrane was, a priori, influenced by the strong or weak forces of adsorption. He suggested that the force of adsorption with ferrocyanide ions was much stronger than with the chloride, sulphate and the ferricyanide ions, and this resulted in the clogging of the pores by the ferrocyanide chains which extended from the surface downward into the pores of the membrane. He visualised further that the chains of the ferrocyanide formed the barrier of a film which was responsible for the anomalous behaviour of ferrocyanide ions. Bhattacharya and Malik[3(a)] in their studies on the diffusion of ions through the ferrocyanide membranes determined the relative values of adsorption which qualitatively supported the view of Weiser regarding the ionic adsorbability and their diffusion through the semipermeable membranes. These observations on the diffusibility of ions through the ferrocyanide membranes may not be strictly applicable to the flow of liquids through the porous adsorbent columns, yet the observations of Weiser are of significant importance in the study of the physico-chemical forces which interfere with the normal dynamic laws of flow in the different types of porous bodies.

EXPERIMENTAL OBSERVATIONS ON THE VELOCITY OF FLOW OF ORGANIC LIQUIDS

Bhattacharya and Gupta[3] visualised that, if the pressure, average size of particles, height of the adsorbent column and the cross sectional area were fixed, the specific effect of the surface property and structure of the liquids, if any, would be reflected in the variations of the velocity or rate of flow. The simple technique which they developed to study this aspect may now be briefly described to explain how the variables were fixed in their experimental device.

The adsorbent was sieved through a 60 mesh sieve and the sieved particles were stirred in the liquid, and packed as uniformly as possible by pouring the suspensions in a chromatographic tube, fitted at the bottom with a sieved porcelain disc. The porcelain disc was covered with a thin pad of asbestos wool to arrest any particle from coming out. The same chromatographic tube was used for packing the column every time to keep the cross sectional area constant. In order to keep the hydrostatic pressure constant, the tube was kept filled upto its rim by a burette device. The liquid was drained through the column by applying a suction force (34.5 cms. height of mercury in a vertical capillary manometer). This was the arrangement to measure the rate of flow by fixing the hydrostatic and suction pressure, average size of the particles, height of the adsorbent column, and the cross sectional area of the column in the tube. It can now be logically argued that any variation in the rate of flow under these conditions from liquid to liquid should be ascribed to the changes in the interior of the column. In other words, the changes in the interior are to be found in porosity, size and shape of the pore spaces or capillary passages. It may be further visualised that the pore size and shape may be appreciably affected by the solid-liquid interfacial forces. Hence, ceteris paribus, the variations in the rate of flow from liquid to liquid through the same adsorbent column may be attributed to the variations in the physico-chemical forces of the system which have their origin in the structural properties of the solid particles and the liquid.

Two other physical quantities which are connected with the velocity of flow are the density and viscosity of the liquid. Bhattacharya and Gupta[3] empirically developed an equation which gave a very significant constant, K, which was dependent on the functional group of the liquid molecules, when the values of K were determined under constant conditions of the height of the column, pressure, cross sectional area and average size of the grains. By plotting the rate of flow $(\frac{v}{t})$ against the inverse of the height of the column $(\frac{1}{h})$ the curve was linear upto an optimum value of h ; similarly, when $\frac{vh}{t}$ was plotted against $\frac{\text{density (d)},}{\text{viscosity } (\eta)}$ a straight line was obtained. Assuming a simple proportionality among these variables, a very simple relation is derived which they have expressed as $\frac{vh}{t} \cdot \frac{\eta}{d} = K$, where K is a proportionality constant which is related to the structural characteristics of the liquid and the surface of the adsorbent. The values of K determined for the members of a certain family of organic liquids passing through the same adsorbent column surprisingly suggest that K depends on the functional group of the molecules belonging to the homologous family.

It may be mentioned here again that according to Darcy the rate of flow was dependent on the pressure gradient and viscosity, while Slichter worked out the proportionality between square of the mean diameter, R, of the particles and the rate of flow. According to their equations the velocity of flow of a liquid should remain the same when it flows through different porous columns having the same mean diameter of particles under the same pressure. If the flow of liquid depended only on the pressure, diameter of particles, and the viscosity of the liquid, the rate of flow for the same liquid should be independent of the nature of the material of the column under equal conditions of pressure and mean diameter of the particles. But the results of Bhattacharya and Gupta[3] showed that the velocity of flow also depended upon the nature of the adsorbents when the same liquid flowed through their columns under constant physical conditions. The figures obtained for the rate of flow of water when it passed through different columns were for calcium carbonate (.0036), silicic acid (.0069), fuller's earth (.0013), kieselguhr (.011) and magnesium oxide (.009). According to these figures the above adsorbents may be arranged in the order of their water transmission capacity as kieselguhr>magnesium oxide>silicic acid>calcium carbonate>fuller's earth. Similar results were obtained for alcohols, esters, ketones and aromatic hydrocarbons where the rate of flow of the liquid and the order of the liquid transmission capacity were found to be specific with the nature of the liquid and the adsorbent column. The foregoing observations obtained under fixed conditions of pressure, and mean diameter of particles were very significant to suggest that the variations in the rate of flow must be due to the changes in the size and shape of the pores and capillaries which depend on the nature of the liquid and solid. In all probability, the interfacial forces between the liquid and the surface of the particles of the adsorbent are responsible for the specific sizing and shaping of the pores in the column.

The velocities of flow $(\frac{v}{t})$ were determined for benzene, methyl acetate, acetone, water and methyl alcohol by passing them through the columns of silicic acid, kieselguhr, calcium carbonate, fuller's earth, magnesium oxide, alumina and calcium hydroxide. The order of liquid transmissions gave interesting evidences to show the importance of surface properties and liquid structure. Through the silicic acid and kieselguhr columns the velocity of transmission can be arranged as C_6H_6>Me-Ac.> Acetone>water>Me-0H. This similarity of the order was in all probability due to the geometrically similar pores and passage of the two systems ; or, in other words, this may be ascribed to the supposed similarity of surface characteristics of silicic acid and kieselguhr. The order of flow through the calcium carbonate column was C_6H_6>acetone>Me-Ac>Water> Me.0H ; for fuller's earth, it was Me.Ac>C_6H_6>Acetone>Me.0H> Water ; and, with magnesium oxide, it was Me.Ac>Acetone>C_6H_6 >water>Me.0H. The foregoing orders of liquid transmissions through different adsorbent columns suggest that the pore factors of these adsorbent columns are appreciably affected by the interfacial forces between the adsorbent and the liquid. Benzene has the highest relative flow through silicic acid, kieselguhr, calcium carbonate, but this is not the case with fuller's earth, and magnesium oxide. The order of flow of water and methyl alcohol is similar in silicic acid, kieselguhr, calcium carbonate and magnesium oxide, but it is not so in the case of fuller's earth. Similar reverses are observed in the relative order of flow of benzene, methyl acetate and acetone by changing the adsorbent columns. These observations are very pertintent to warrant the fact that the surface and structural characteristics play a very important role in the flow of liquids through these porous columns. Another striking observation was that the non-polar liquids in general could pass through the porous columns more quickly than the polar ones. Benzene, for example, which is non-polar, had a greater rate of flow through the columns of silicic acid, kieselguhr, fuller's earth, calcium carbonate and magnesium oxide than the velocity of transmission of the polar molecules of water and methyl alcohol.

The role of the functional group or groups in the liquid molecules was very remarkably shown by the values of K evaluated from the equation, $\frac{vh}{t} \cdot \frac{\eta}{d} = K$. It provided a positive evidence of the fact that there is some specific relation between the velocity of flow, η and d of liquids and the characteristic functional group of a family of organic compounds. Under the constant condition of the known variables, K was found to be constant for a particular family like alcohols or ketones or esters etc. Each family was found to have their specific and constant value of K for the particular adsorbent, and it changed to give another constant, only when the homologous family was changed. Similar was the case when adsorbents were changed for the same family of liquids. This fact will be clarified further when the actual figures of K for alcohols, ketones, esters, and aromatic hydrocarbons flowing through calcium carbonate are taken up for reference. 'K' of $CaC0_3$ for methyl, ethyl, propyl, butyl and amyl alcohol was found to be 0.0114 (a constant) to the nearest limits of experimental error. Similarly,

Alcohols	esters	ketones	Aromatic hydrocarbons
$K(A1_20_3)=0.016$,	$K(A1_20_3)=0.0086$,	$K\ (Al_20_3)=0.0142$,	$K(Al_20_3)=0.0342$.

The velocity of flow of these families of liquids through the fuller's earth, kieselguhr, silicic acid and sugar charcoal was also studied by Bhattacharya and Gupta and the results were similar to those as given above. This leads to support their proposition that the structural factors and functional groups have some correlation with the rate of liquid transmission through the porous columns.

Since the volume of flow $\frac{v}{t}$ per unit time varies inversely as the height of the column, the expression $\frac{vh}{t}$ may be defined as the volume of liquid which passes through the unit height of the column in unit time. If this simple interpretation of the expression $\frac{vh}{t}$ is admissible, its relative values enable us to compare the liquid transmission capacity of different porous columns by fixing the other variables of the system. For example, the relative values of vh/t of different families through silicic acid and calcium hydroxide columns are as 1 :1.58 (alcohols), 1 :2.9 (esters),1 :3.7 (ketones), and 1 :2.01 (aromatic hydrocarbons). These figures clearly indicate that the calcium hydroxide column is more porous than silicic acid and the porosity as well as the shape and size of the pores differ according to the family of organic liquids which are made to flow through the adsorbents. When the fluid and suction pressure, size of grains and temperature are fixed and packing of grains are assumed to be uniform, the only other variables which may alter the rate of flow are the porosity, size and shape of the pores in the column. These differences in the rates of transmissions through different columns can, therefore, be only attributed to the interfacial forces which ultimately depend upon the polarity and structure of the liquid molecules and the particles of the column.

The important role of functional groups on the flow of organic liquids was further evidenced by taking mixtures of organic liquids belonging to the same family. In view of the complexities which generally arise in the viscosities of mixed liquids, it is difficult to anticipate that mixed members of the same family would give the same value of the constant K as that of the pure components. None-the-less, the experimental results showed that the values of the constant ' K ' for the mixtures of methyl-ethyl, methyl-propyl, methyl-butyl, methyl-amyl and propyl-butyl alcohols were the same as the constant calculated for the homologues of the alcohol family. Similar results were also obtained for the mixtures of esters, ketones and the aromatic hydrocarbons. These observations again give a reassuring evidence of the part played by the functional group in the transmission of liquids through adsorbent columns.

A more interesting evidence of the dependence of the velocity of flow on the structure of liquid molecules was obtained in the behaviour of the ortho- meta- and para compounds. It was observed that the velocity of flow through a particular column was appreciably altered by the group in the ortho, meta, and para positions. o-meta nitrotoluenes, o-m-para chlorotoluenes, o-m-para xylenes, o-meta chloroanilines, o-meta toluidines, o-meta anisidines and o-para phenatidines were made to flow through the packed columns of seven different adsorbents, $CaCO_3$, MgO, Al_2O_3, fuller's earth, kieselguhr, silicic acid, and animal charcoal under the controlled conditions as in other experiments and it was observed that the velocity of flow of these isomers was appreciably altered by the ortho-meta and para positions of the substituent groups. The values of $\frac{vh}{t}$ suggest that there is a definite order in the rates of flow of the ortho-meta and para liquids for all adsorbents depending on the nature of the substituents in the aromatic ring. On the basis of experimental data the above mentioned liquids could be classified into two groups—(i) those in which the values of $\frac{vh}{t}$ had the order, ortho$>$meta, as in the case of nitrotoluenes, chloro-anilines, phenatidines and anisidines, and (ii) those in which the values of $\frac{vh}{t}$ had the order, ortho$<$meta$<$para, as in the case of xylenes, chlorotoluenes, and toluidines. Such a regularity in the order of the flow of the isomers in all adsorbents is very significant to establish the fact that the structural properties of liquids contribute appreciably to the velocity of flow to which hardly any serious attention had been paid by the previous workers.

The available data on dipole moments of these isomers have thrown some light on the correspondence betwen the orders of flow and the dipole moments of ortho, meta and para liquids. In some cases the values of vh/t for the ortho-meta and para liquids decrease with the increase in their dipole moments, while, in others, vh/t has been found to decrease with the decrease in the dipole moment of the isomers. No generalisation, however, can be warranted at this stage till more extensive work on the flow of substituted aromatic liquids is carried out and correct values of the dipole moments are available for all liquids.

PHYSICAL INTERPRETATIONS OF THE PROPORTIONALITY CONSTANT, K, IN THE EMPIRICAL EQUATIONS FOR THE RATE OF FLOW OF LIQUIDS

Having discussed the experimental results which have given significant evidences for the relation between the structural and surface forces and the proportionality constant in the equation $\frac{vh}{t} \cdot \frac{\eta}{d} = K$, it now remains to deduce whether it is supported by the physical interpretations and dimensions of the constant, K. It can be readily shown that the equation $\frac{vh}{t} \cdot \frac{\eta}{d} = K$, is a particular form of the original Darcy's equation in which the density and viscosity of the liquid have been introduced as essential parameters.

M. King Hubbert[8], an eminent American Geophysicist, in an interesting article on Darcy's law points out that Darcy's equation plays the same role in the theory of conduction of fluids through porous bodies as the Ohm's law in the conduction of electricity. But Darcy himself did not explain anything about the physical aspect of the phenomenon of flow in his equation. Consequently, Hubbert discussed what changes would be effected, if liquids having different densities and viscosities flowed through a porous column and in what manner the proportionality constant 'K' would be affected by the measurable statistical parameters of the particles, such as their coarseness and shape. By logical analysis he observed that 'K' was a lumped parameter comprising the geometrical properties of the grains, the dynamical properties of the liquid and the action of gravity. He expressed the proportionality constant in the form $K = N.R.^2 \frac{d}{\eta} . g$, where N is the final factor of proportionality, R, the mean diameter of the grains, d, the density of the liquid and η the coefficient of viscosity. By dimensional inspection Hubbert observed that N was dimensionless, and, since no dynamical variables had been omitted in the equation, he concluded that the proportionality constant, N, was related to the only remaining variable which is the shape of the passages through which the flow occurs. Since the shape is expressed by angular measurement and angles are dimensionless (L/L), the shape factor, N, must have no dimension. The shape factor is attributed to the geometrical arrangement of the particles which, in the light of the evidences already discussed, should be affected by the surface forces and the structural characteristics of the molecules also ; but this aspect of the problem does not seem to have been paid any serious thought by the hydrologists or geophysicists who, in fact, are responsible for the remarkable contributions in this field of research. In evolving a mathematical equation for any physical phenomenon involving a proportionality constant, it is generally expected that the constant K should have no dimension. When this is achieved there is a sense of satisfaction for the theorist that all the independent variables on which a particular property depends have been duly considered and the dependent and independent functions have been dimensionally balanced. But when some variables remain undefined, it is not very unusual to obtain dimensional constants also. It is, therefore, necessary to probe into the dimensional aspects of the empirical equations on the velocity of flow of liquids given by Darcy, Bhattcharya and Gupta.

Putting Darcy's equation in the form $V = \text{const.} \frac{d^2}{\eta} \cdot \frac{dp}{dx}$ where V is the volume of liquid transmitted per unit time, d, the effective diameter of the grains, η the viscosity of the liquid, and $\frac{dp}{dx}$, the pressure gradient, it is found that the dimension of the constant is L^2. This immediately suggests that Darcy did not take into his consideration the role of the surface forces which play their part in the solid-liquid system. Assuming the surface forces to be proportional to the total surface area of the column, Darcy's equation may be put in the form $V = K. \frac{d^2}{\eta} . \frac{dp}{dx} . S$ where S stands for the total surface area of the column in contact with the flowing liquid. Now, by dimensional inspection, K becomes dimensionless. From the foregoing treatment it becomes evident that, among other factors, the surface of the column in contact with the flowing liquid is an important factor to be considered in determining the velocity of flow of liquids through porous columns.

The equation, $\frac{vh}{t} . \frac{\eta}{d} =$ const. may, likewise, be treated, and it will be found that the constant in the given form of the equation has the dimension of $\frac{L^6}{T^2}$. Hence it means that the constant contains such parameters as are lumped together to make its dimension $\frac{L^6}{T^2}$. Since the dimensions of the gravity, surface, and volume of the pores are $\frac{L}{T^2}$, L^2, and L^3 respectively, it appears that these dimensions remain hidden in this constant. Therefore, with plausible assumption, if these parameters are put in the equation, the constant becomes dimensionless. The equation then takes the form, $\frac{V}{t} = K. \frac{l}{h} . \frac{d}{\eta} g. S. v.$ in which the constant ' K ' becomes dimensionless. The dimensional treatment of these empirical equations, therefore, leads to the conclusion that the velocity of flow of liquids, $\frac{V}{t}$, depends upon the characteristic surface properties of adsorbent columns and the total volume, v, of the pores. The question of the molecular structure and functional groups remains, however, unrevealed, because the physico-chemical forces of molecular orientation, film formation and adsorption do not come within the purview of the theory of dimensions. Evidence for such forces may be obtained from the thermodynamic properties of the liquid-solid interface.

DETERMINATION OF THE RATE OF FLOW OF LIQUIDS AND POSSIBLE APPLICATIONS

While I reflect over the possible applications of the rate of transmission of liquids through a porous column, I am fully conscious of the tentativeness of my speculations. None-the-less, the knowledge of fundamental science has gone a long way to bridge the gulf between theory and practice by long perseverence and systematic experimental efforts. This is my plea for taking indulgence to suggest that studies on the velocity of flow should be put to rigorous tests in characterising the geological sediments and stratified rocks. Geologists deal with intricate problems on the internal structures of the earth's crust and flow of water, oil, and gases through the pores and channels of the underground layers. The sedimentary rocks vary in their composition according to their origin which are classified into the groups of (i) clastic, (ii) organic and (iii) chemical deposits. The clastic deposits comprise the gravels, sand, silt and clay. The organic deposits are composed of the decomposed residues of plants and animal remains which ultimately turn into the sources of petroleum, while the chemical deposits are mainly the precipitated minerals, such as silica, alumina, iron and other mineral ores mixed up with soluble salts. From the composition of these sediments it is evident that they possess specific physico-chemical properties and structural characteristics by virtue of which the velocity of flow would be affected under conditions of proper control. This forms the basis of my anticipation that the rate of transmission of a particular liquid through the sample columns of a definite size and shape dug out of the sedimentary rocks may furnish a suitable index for their characterisation. Experiments based on this line with the dug out samples appear to be the nearest approach to the conditions of packing in situ. It may be worthwhile also to pulverise and sieve the materials to keep the grading of size constant and pack the column artificially or by some mechanical means to make the packing conditions as uniform as possible. The velocity of flow of a liquid determined by keeping the temperature and pressure constant may give different values of the constant, K, for different sediments characteristic of the structure of the columns and their physico-chemical properties.

The prevaling opinion of geologists in the past was that India was poor in mineral resources, and this seems to be the reason why the scientists of India had kept themselves away from exploring the possibilities of her mineral resources. But the recent results of geological prospecting by the Indian and Soviet geologists have enabled them to chart out several oil and gas bearing areas in our country. They have further reported that India is an integral part of a large basin of promising sedimentary rocks stretching throughout the Arab countries and central Asia. In view of these hopeful prospects, the need for stepping up investigations for the economic welfare of our country cannot be too strongly emphasised. From the angle of a pure chemist I feel that, if experiments are conducted on the flow characteristics of a liquid through the sedimentary rocks, the geologists may discover one more suitable index to supplement the existing ones for spotting out the organic deposits and petroleum beds, wherever they exist. I am, however, afraid that these suggestions coming from one, who is not a geologist, may be considered a wild ramble without a legitimate passport. If it is so, I tender my apology for rushing into a realm where angels fear to tread.

In the light of the prevailing view of the soil physicists water movement in soil takes place through the capillaries of the small pores as well as through the passages of larger ones. These movements are brought about by the action of gravity or capillary pull, either alone, or in combination, according to the size of the pores of the system. But the movement or transmission of liquids through the porous columns which has been presently discussed elicits further that the flow of a liquid also depends on a new variable which finds justification in the surface properties of the material of the column and the structure of molecules. This observation leads to the agreeable suggestion that any characteristic physico-chemical change brought about in the soil may be indicated by the variations in the velocity of flow of a liquid. This liquid, if used as a reference, comparative data under identical conditions may be obtained for the variations of the soil properties.

Soil is a dynamic body of composite nature which has been changing its character very slowly and continuously according to the geographical, and climatic conditions. The soils are usually characterised by their (i) clay minerals, (ii) clay content, (iii) organic matter, (iv) mineral salts, (v) soil structure, (vi) exchangeable bases and (vii) size distribution of the particles. Since there are so many variables, it is difficult to determine which of them have suffered a change due to weathering, hydration, or chemical decomposition, and to what extent these changes have been brought about. Nonetheless, the velocity of flow will vary depending upon the variations in one, two or all the conditioning factors which characterise the soil. Thus it follows that, if a reference liquid, say benzene, is made to flow under identically controlled condition through a column of the soil, the velocity of transmission or the constants calculated from the equation $\frac{vh}{t} \cdot \frac{\eta}{d} = K$ will serve as an index for the variations in the structure of the soil brought about by physical and chemical changes.

Interesting references of the velocity of solvents through the adsorbent columns are found in the development of chromatography. Le Rosen evolved a method for the standardisation of adsorbents by determining the relative rates of the movement of a zone (mm/min) and the rate of flow (mm/min) of the developer. The ratio of the rate of movement of the zone and the rate of flow of the developer, Vc, when a constant flow has been reached, gave a certain value which was designated as R, where $R = \frac{\text{rate of movement of the zone}}{\text{rate of flow of the solvent (Vc)}}$. The approximate strength of the adsorption affinity has been characterised by the value of R. Le Rosen's R is equivalent to RF of Martin and Synge. Hence, the value of the velocity of flow of solvents through adsorbent columns finds its use in chromatography in which its significance has proved to be of a far reaching character.

The elution of colouring matters in paper partition chromatography depends upon the relative movements of the adsorbed zone and the eluant. Jacques and Mathieus[9] observed that the eluting power of the solvents was proportional to their dielectric constants, and the movement of the adsorbed zone was due to the adsorption of the eluant and displacement of the zone by this solvent. Eluants have thus been standardised by studying the relative rate of movements of the eluting solvent and the adsorbed zone.

Our ideas on the subject of the motion of fluids and of the resistance experienced by bodies exposed to a current of liquid came from Newton, who envisaged the flow over a solid boundary as being characterised by a gradient of velocity and a condition of rest for the liquid in contact with the boundary surface. The successive layers move with faster and faster speeds until the speed of the free stream is attained. The liquid is thereby strained and a shear is produced in the same way as a slab of jelly is sheared. The rate of shearing is proportional to the velocity gradient, but it also depends on the physical properties of the liquid. This concept does not, however, take into account the intrusion of any kind of undefined force which may affect the flow property of the system. The forces of physico-chemical nature, such as interfacial tension, molecular orientation, adhesion and cohesion, sorption and adsorption may appreciably influence the flow and bring about an adjustment of the rate of shearing with the velocity gradient. This is what probably happens, when the liquids are made to flow through the capillaries of different adsorbent columns. The undefined forces at the surface of contact may be primarily governed by the structure of the molecules with their functional group and the characteristic surface forces. If this assumption is admissible, the velocity of flow would so adjust itself with the viscosity and density of the liquids that the same constant value would be obtained from the equation $\frac{vh}{t} \cdot \frac{\eta}{d} = K$, for liquids belonging to the same homologous family. This fact has been confirmed by experimental results.

Among the applications of the equation $\frac{vh}{t} \cdot \frac{\eta}{d} = K$ it may be quite interesting to visualise the significance of K, as a structural constant like parachor or rheochor. The density (d) of the liquid being in the denominator suggests, ceteris paribus, that K is the specific constant for the flow of a family of organic liquids. Hence, if the values of K for the alcohols, esters or ketones are multiplied by the molecular weights of the ascending homologues, the products should give a constant difference due to the addition of a CH_2 group from member to member. This has been actually observed, but one must be cautioned to declare a fixed value for these constants as well as for the differences of the products, because there is no method of checking up whether the arrangement of particles regulating the size and shape of the pores are identical or not. If it were so, there would have been a possibility of the emergence of a new physical constant (fluidochor?) for the liquids from their velocity of flow through the adsorbent columns. I may be excused, however, for such unwarranted optimisms, but nothing is impossible in the present age of scientific developments.

Ladies and Gentlemen,

My peep into the hidden stream lines of a porous column is now nearing the journey's end. I fully realise that my attempt to probe into the pores of the adsorbents has made you suffer no less tedium of the journey than my own self. Your patient hearing and unique courtesy in listening to the ticklish evidences of the variations in the rate of flow with the structure of the liquid molecules and surface properties have filled my heart with a sense of gratitude which I can never repay. It is a hard problem of hydrodynamics and the need of including the undefined physiso-chemical forces in the parameters of the mathematical equations will make the problem harder still. Yet, the fact should not be forgotten that Nature presents to our senses a panorama, co-mingled in endless variety, which overwhelms our limited power of reasoning. It is for the scientific judgment to arrive at logical conclusions from the experimental facts which I have portrayed and to differentiate betimes the accidental or transient attributes from the essential and law abiding ones. The subject of the rate of flow of fluids through porous media had been developed by the Engineering, Mathematical and Geophysical schools of research, but now a chemist intrudes to sing his solo without any accompaniment of music to harmonise his lonely tune. Courage and conviction must not, however, lag behind, and I grow stronger in my belief that the solo of today will turn into a chorus, sung by my brothers tomorrow, when they practise the art and observe the facts themselves. "The divisions of Science", said Bacon, are like the branches of a tree that join in one trunk," and thus the summum bonum may be achieved when the Engineers, Mathematicians, Geophysicists and Chemists play their tunes together in harmony. Science seeks a complete knowledge and a perfect unison of all its branches but the target appears to recede, as knowledge develops in water-tight compartments. So, in our quest for truth, like Tennyson dawns in my mind his confession :—

> " So runs my dream ! But what am I ?
> An infant crying in the night ;
> An infant crying for the light ;
> And with no language, but a cry."

Such is the limitation of our knowledge, yet we must cry for Science to know the secrets of Nature.

Thank you !

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SECTION OF GEOLOGY AND GEOGRAPHY

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PRESIDENTIAL ADDRESS

IGNEOUS ACTIVITIES AND PERIODS OF OROGENESIS IN GONDWANALAND

It is a great pleasure and privilege for me to preside over the Geology and Geography section of the 47th Session of the Indian Science Congress in this great city of Bombay where my revered *Guru*, the late Prof. K. K. Mathur, who initiated me in the study of the mysteries of the earth, presided just quarter of a century ago. I am proud to say that the school of Geology which was established by him has contributed five Presidents to this section during these last 25 years and many more are to follow. In that session in his presidential address[1] he dwelt upon the late Cretaceous and early Tertiary igneous activity in India, in the study of which I had the honour to be closely associated with him. This time in my presidential address I shall carry the study of the igneous activity much farther in time and space covering Australia, India and Africa which are said to have been connected forming a vast continent called the 'Gondwanaland'.

A vast progress has been made in the Science of Geology since the time when Prof. Mathur addressed this Section in this town. In the science of geology, the study of the present has led us to form ideas about the past, that is to say, the present has served as the key to open the door of the mysteries of the past. In this connection the study of the latest igneous cycle in India has given us some ideas about the past cycles and has been of great help in their study. In the past, the only method of correlation of rock formations of different continents has been the study of fossils found in them. But due to certain causes, still not clearly understood, many formations are devoid of fossils making the correlation difficult. Besides this, the fossils which can be the basis of stratigraphical correlation have only come on the stage at the beginning of Cambrian times. But we know now that the Cambrian period began only about 500 million years ago, while according to the latest estimate the age of the earth is somewhere between 3000 and 3500 million years. Thus, the period from the Cambrian till now covers only 1/6th or 1/7th of the history of our mother earth. The study of fossils has therefore not carried us very far in ascertaining the greater part of the history of the earth, and for the detailed study of the Pre-Cambrian period some other methods are essential.

Fortunately for us the science of physics has made tremendous progress during the last 25 years and new methods developed by that science have been utilized by the geologists for their own purpose. With the help of these methods we have been able to determine the age of the rocks and minerals in a quantitative way and a new branch of nuclear geology has come to existence. The methods of determination of age in years have their origin in the 20th Century. For the first quarter of the century the only available method for age determination was based upon the decay of uranium and thorium minerals. These minerals disintegrate at a constant rate and give rise to the end product lead. This method gave us the age of those rocks or formations in which these radioactive minerals were present but unfortunately for us such formations were rare. A large number of formations are devoid of such minerals. The other difficulty was that most of these minerals had some original lead present in them. Thus all the lead determined chemically was not of radioactive origin. No doubt it was a great improvement over the older methods, but still the method could not be said to be perfect till the method of determination of isotopes of elements by mass spectrometer was evolved. With the determination of uranium and lead content of the radioactive minerals together with the isotopic determination of lead it became possible to find the true age. Besides uranium, thorium minerals were also utilized for the same purpose. A great amount of data was collected by Prof. A. Holmes on the age of the rocks belonging to different periods in different parts of the world and thus geo-chronology in millions of years has arisen. But even then the method remained confined to a few formations only which contained radioactive minerals. In 1929-30 the speaker, while working on the radium content of the Indian igneous rocks at Vienna and on their helium content in the laboratory of Prof. Paneth in Berlin, established for the first time the helium method for the determination of age of the fine-grained igneous rocks, which are far more plentiful in nature than the radioactive minerals. This new method has far wider applications than any other method existing till then. The speaker, on his return to India, unfortunately could not continue this work due to lack of facilities but the study of the age of the rocks by this method was taken in right earnest by the Americans, who found that even in fine-grained rocks a part of helium escapes, hence the age given is minimum. But because some minerals like magnetite have got the power of retaining helium to a great extent, so the helium method gives a reliable age in the case of formations containing magnetite.

The third method is based upon the disintegration of rubidium into strontium. This method has been developed mainly by Prof. Ehrens who worked at M.I.T. till 1953 and thereafter at Oxford. Most of the micas are rich in potassium and also contain some amount of rubidium which has been disintegrating to produce strontium. A large number of age determinations[2] have been carried out by Prof. Ehrens on mica-containing pegmatites coming from different parts of the world. These have given fairly reliable results. Discrepancies, however, do occur. The speaker had the privilege of coming in contact with Prof. Ehrens in 1953 when he was working in M.I.T. The fourth method recently developed is based upon the transformation of potassium into argon by disintegration. Though this method is a recent one, it has given quite reliable results and a large number of age determinations have been made by this method. The rocks and minerals containing potassium are quite abundantly distributed in nature and so this method has a very wide application. The potash feldspars are the most common minerals in majority of igneous rocks and they have been utilized for the determination of their age. The results given are fairly reliable and compare quite favourably with the age determinations by other methods.

During the last quarter of this century all the above-given methods have been utilized for the determination of the age of rocks in different continents[3] and thus we have now before us a vast amount of data on the basis of which correlation of the formations of different continents can be established. Although the data on the age determination of different Indian formations are not so exhaustive as in other countries, it is quite enough for making an attempt on the correlation of igneous activities and the periods of orogenesis in the different continents once constituting the Gondwanaland. The speaker has tried to collect as much data as possible on the age of the rocks and has made an attempt to correlate the rock formations, igneous activities and the periods of orogenesis in the old Gondwanaland now represented by Africa, Madagascar, India and Australia.

In India the latest igneous cycle began with the outpouring of basalt in the upper Cretaceous and this eruption lasted till the lower Eocene period. At the end of Cretaceous also came the intrusions of ultrabasic rocks on the West, North and East periphery of this vast continent. The ultrabasic rocks of this period, i.e. from the Upper Cretaceous to the Lower Eocene, are found in Baluchistan, Kashmir, at many places in the Himalayas, in Burma and Andaman & Nicobars. It is not possible in the short space to give the details of all the occurrences, but it is more or less certain that an ultrabasic igneous activity took place on the border of the continent and it is quite possible that a branch of it penetrated Western India and gave rise to ultra-basic rock masses of Cutch and Kathiawar. These Western India occurrences were described in detail by Prof. Mathur[4] in his presidential address in 1934. It is quite possible that some of these ultrabasic masses in Western India might have originated by magmatic differentiation of the Deccan Trap magma but a part of these might have had their origin from the ultra-basic shell of the earth also because this magmatic differentiation cannot explain the presence of these ultrabasic rocks in Baluchistan, Kashmir and in other north-eastern regions of India. There is not much difference in age between this ultra-basic activity and the Upper Deccan Trap activity proper. After that came the period of great orogeny in middle Tertiary times which gave rise to the Himalayas. During this period of orogeny vast amount of granite was intruded along the border of the continent now constituting the Himalayan range. It is very likely that the acid intrusions of Kathiawar, Western India and even in areas as far as Bombay belong to this period. There is clear evidence to prove that vast erosion of Deccan Trap amounting to about 2400 ft.[5] had taken place at the time of the acid intrusions and this evidence along with other evidence makes it highly probable that these acid intrusions belong to middle Tertiary age. Thus, this whole igneous cycle, which began in the Upper Cretaceous period lasted till the Middle Tertiary. The total duration for this cycle will be about 40 to 50 million years. In Africa, we do not find a great activity of plateau basalt type, but a great ultra-basic activity represented by Kimberlite took place at the close of the Cretaceous, i.e. at the same period in which the ultra-basic rocks of Baluchistan and other parts of India were erupted. A great part of South Africa was perforated and a green-bluish ultra-basic material known as Kimberlite[6] came out which is the source of diamond. There is enough evidence to prove that the ultra-basic activity giving rise to Kimberlite extends to a great part of Africa. These ultra-basic rocks have drawn the attention of geologists on account of their economic importance. This Kimberlite contains at times lumps of granulitic rocks, of high specific gravity, ranging from a few inches to a foot, in length. Thus it is clear that while ultra-basic rocks were being intruded in India, an activity of similar kind was taking place in Africa. In this connection it may be said that during same period in Australia,[7] i.e. in the Upper Cretaceous, we have an important volcanic display which produced the Graham's Creek volcanic series in south-east Queensland consisting of unknown thickness of rhyolite, trachyte and andesite tuffs. In eastern New South Wales[8] a series of teschenitic intrusions are encountered in south-east Queensland, New South Wales, and it is highly probable that they were injected in the late Cretaceous folding but may also be of early Tertiary age. A large amount of basalt was also poured out in the early Tertiary times. There is no doubt that the period of the Upper Cretaceous and the Lower Tertiary was one of igneous activity in Africa, India, Australia and also South America. The period of this activity will be somewhere from 60 to 30 million years.

In India the igneous activity which preceded this Deccan Trap activity belongs to the Rajmahal series. To this activity we owe the Rajmahal basalts and most probably the Sylhet Trap[9] is a continuation of these Rajmahal Basalts. They have been assigned an age in Indian Geology which corresponds to the Jurassic[10] period. Thus their age will be somewhere between 130 and 150 million years. The other volcanic activity which occurs nearabout this period is represented in the Pir Panjal range in Kashmir. The age of this activity is from Upper Carboniferous period to Upper Triassic and thus its range will be about 230 to 170 million years. It appears that both of them belonged to the same cycle of igneous activity, one preceding the other slightly, somewhere about 200 million years ago. This was the only igneous activity which took place during the whole of the Gondwana era in Peninsular India extending from Upper Carboniferous to the Lower Cretaceous. This activity may well compare with the igneous activity in Madagascar which belongs to an age group of 225 million years.

Now we shall consider what was happening in other parts of Gondwana land during this era. The Gondwana system in India corresponds to the Karoo system of South Africa. This Karoo system in Africa begins with the Dwyka Glacial Boulder Bed of Upper Carboniferous age and extends upto the lower Cretaceous age.

A large amount of work has been done in correlating the flora and fauna of this Karoo system with the Gondwana system of India, and their contemporaneous nature is well established.[12] During the period of Stormberg series of this system a vast volcanic activity took place in South Africa and gave rise to Drackenberg basalts, the thickness of which amounts to about 5,000 ft. The greater part of this is formed by lava flows, though at times beds of volcanic ash are also encountered. The activity of this period can well compare with the size of the activity of Deccan Trap in India and has the same petrological characters. The age of this Drackenberg activity is from Rhartic to Lias or about the same as that of the Rajmahal basalts. It may be about 140 to 150 million years.

In Australia, which is also supposed to have been a part of the Gondwanaland, the Upper Carboniferous period is marked by a thick bed of tillites, which corresponds to Talchir boulder bed of India and Dwyka boulder bed of South Africa. Here glacial conditions began somewhere in the later part of Carboniferous times and reached its intensity in the Upper Carboniferous period. While glaciation[13] was going on, there was energetic volcanic activity in land surface of New South

Wales, and lava and volcanic ash intermingled with lake deposits. It appears that the age of this volcanic activity is same as that of Pir Panjal the age of which is supposed to range from late Carboniferous to the Upper Triassic, i.e. from 225 million years to 165 million years. This volcanic activity was quite wide in eastern Australia and in New South Wales. This activity seems to be of a slightly earlier period than the igneous activity of Rajmahal series and Stromberg series. This activity may be about 225 million years old. On the whole, this volcanic activity of Gondwanaland may be given an age somewhere from 225 million years to about 140 million years. This period will cover all the igneous activities occurring in the Gondwana formations in India, Karoo formation in Africa, and the Upper Carboniferous, Permian and Triassic formations of Australia. In Eastern India (Bihar) and Africa which were stable land this basic igneous activity has only come on the top, while in Australia and Kashmir in India it began in Upper Carboniferous period and continued upto the Triassic period. The period of 50 or 60 million years assigned to this activity at Pir Panjal centre in Kashmir can well compare with 50 or 60 million years of Tertiary igneous activity in India. On the whole a great part of stable Gondwana formations in India and formations of the same age in Africa and Australia enjoyed calm and stable conditions except at the end when basic igneous activity broke out.

UPPER PRE-CAMBRIAN IGNEOUS CYCLE

Now we proceed to the igneous activity which preceded the one described above, i.e. of Gondwana times. In India basic lavas of Gwalior, Bijawar and Cuddapah[14] are seen spread throughout the country. Beginning from the west, the lavas near Hindon, the dolerites near the town of Gwalior, the basic lava flows extending from the town of Bijawar upto the river Ken, the basic rocks spread throughout the Sone valley newer dolerites of Singhbhum, lavas of Cuddapah period of South India, large number of dykes found in almost the whole of Southern India,—all these represent the igneous activity of this Cuddapah period. In extension this igneous activity can well compare with the Deccan Trap. The speaker himself has carried out the studies of this Trap in Gwalior,[15] Bijawar, Sone Valley and other areas of Northern India. This activity was followed by the intrusions of ultra-basic rocks and then of granites and outpouring of acid lava flows. We will give it a name of Upper Pre-Cambrian igneous cycle. Before correlating this activity with that of Africa and Australia, it will be essential to fix its exact age in India. A lot of controversial literature has appeared about the age of this formation. Some authors[16] have taken it to be contemporaneous with the Upper Dharwars, while others with the Delhi series.[17]. But enough data have accumulated now to prove its real age. This is based upon the world-wide glaciation[18] which took place at the end of the late Pre-Cambrian and just before the beginning of the Cambrian. In India very little was known about the glaciation during this period. Early workers like Oldham and Blandford have described these boulder beds as looking like the glacial boulder beds.[19] But the speaker and his pupils working on the Bijawar formations have clearly established the presence of a definite tillite bed. Mr. M. S. Chaudhary,[20] one of the pupils of the speaker, has mapped out this tillite bed which is spread over a length of 50 miles. It begins on the east where the river Ken crosses the Bijawar formations. It is about 250 ft. thick and occurs just above the basalt flows of Bijawar period. Over this tillite bed lies the Semri series with slight unconformity. This series represents lower part of Vindhyans. The age of the Bijawar traps as determined by helium method by the speaker amounts to about 500 mililon years. It may be slightly older and may go upto over 550 million years or so. Thus the age of this glacial formation in India will be about 500 to 550 million years. The same age has been assigned to it in Australia.[21] If we study the geology of Australia, Africa and South America, as well as other parts of the world, we come to know that just before the Cambrian and at the end of the Upper Pre-Cambrian there was a great world-wide glaciation. In Australia it is well represented in the Upper Adelaide system and its equivalents and is known as Sturtian tillite. This has been very well described in the Geology of Commonwealth of Australia.[22] These beds are very thick, and there is not the least doubt that they represent this great ice age. In Africa the Nama system which represents the Upper Pre-Cambrian period also contains a tillite bed named as Numees tillites and the Griquatown tillite. Their age is also Upper Pre-Cambrian coming just below the Cambrian. Thus there cannot be any doubt that this Bijawar tillite is more or less contemporaneous with the tillite bed of Australia and Africa. This Sturtian glaciation[23] was a part of world-wide happening, traces of which besides India, Africa and Australia are also found in China and Siberia. This discovery of Bijawar tillite further confirms strongly that India also had an ice age which was a part of that world-wide glaciation. The age of this Sturtian tillite in Australia is slightly older than the beginning of the Cambrian—because the fossiliferous Cambrian overlies it conformably, though a few thousand feet of unfossiliferous rocks intervene between this tillite and the well-established Cambrian fossiliferous rocks. The age[24] of this tillite bed will be somewhere between 500 to 550 million years. In India this Bijawar tillite overlies the lava flows of Bijawar age. Thus the age of the Bijawar lavas appears to be slightly more than the age of this tillite and may be a little over 550 million years. This discovery of tillite associated with Bijawar basalt clearly establishes the fact that the age of this Cuddapah igneous activity is between 500 to 550 million years. From this it will be clear that the Cuddapah system is of much later date than the Delhi system, the age of which is about 735 million years[25] as determined by the radioactive data and it is much later than the Aravalli system the last uplift of which may be about 955 million years. Now we will try to trace up the detailed history of this igneous cycle in India before taking up its correlation with similar formations in Africa and Australia. After the outpouring of the Bijawar lava there came the intrusion of ultra-basic rocks. The diamondiferous Kimberlite-like rock found in Majhgawan plug near Panna belongs to this period. This plug is surrounded by Kaimur sandstone and has been studied by the speaker. The junction at the periphery of this plug with the sandstone is very sharp. Not a vein of this ultra-basic rock penetrates the sandstone. Not a single piece of sandstone xenolith has been found in this rock though thousands of tons of this material have been dug out. Xenoliths of Bijawar basalts have been found in it in plenty proving that it is later than the Bijawar traps. According to the speaker's view these Kaimur sandstones were deposited all round the plug when it was standing as a hill. In Sone valley near about Sidhi town the ultra-basic rock is found intruding the Bijawar system. In South India also the ultrabasic rocks of Karnool system which are the source of diamond belong to this very age. The Mahanadi valley diamond nearabout Hirakud are also derived from the ultrabasic rocks of this period. After this ultrabasic intrusion there came a period of folding accompanied by the intrusion of granites. There is no doubt that at the end of Bijawar period there was the intrusion of granites as they are found cutting the Bijawars near the town of Bagh in Central India, in Sone valley and even Karnool formations of South India. Thus the igneous cycle which began about 550 million years ago ended about 500 million years ago. In Central India, in Ken valley the Semri series just overlies the tillite bed which represents the upper Pre-Cambrian world-wide glaciation, and being slightly older than the Cambrian may represent an age of about 550 million years. There is only a slight unconformity between this tillite bed and the beds of Semri series overlying it. The Semri series[26] represents the lower beds of the Lower Vindhyans and thus the Lower Vindhyans began slightly less than 500 million years ago which means that the lower Vindhyans are homotaxial with the base of the Cambrians. In Lower Vindhyan period there was a great igneous activity which is represented by the beds of porcellanite found extending over a distance of more than 300 miles along the Sone valley. The speaker has studied this rock in detail and more than 20 chemical analyses are available. The composition is similar to rhyolite and there is clear evidence, that throughout the Sone valley the acid igneous activity continued during the Lower Vindhyan period. While this acid activity was continuing in Sone valley, the rhyolites at the same time were being poured out in Western Rajputana[27] to which the name of Malani rhyolite has been given. Besides the rhyolites, the intrusions of granites also occur at the same period,[28] though they may be of slightly later age than the flows of rhyolite. There is evidence of folding at the end of the Lower Vindhyans and the Upper Vindhyans which were deposited over the tilted Lower Vindhyans, are still lying horizontally. To recapitulate the history of this igneous cycle, we can say that just before the great ice age a basic igneous activity began on a very large scale over the whole of India. It was followed by the intrusion of diamondiferous ultrabasic rocks in different parts of India, and then came the acid igneous activity in the form of rhyolite flows and intrusions of granite. The age of this igneous cycle would range between 550 to 450 million years and will cover a period beginning with the basic igneous activity of the Cuddapahs upto the end of the lower Vindhyans. From this time, i.e. somewhere from about 500 milion years to 550 million years upto the Jurassic period i.e. 150 million years, there was complete quiescence in this part of the world. Thus, the total duration of this igneous activity would be somewhere 50 to 100 million years, and then followed a period of complete quiescence for the next 300 million years in the Peninsular India.

Now we take up the study of Africa as it was during this period. The Nama Transvaal system represents the Cuddapah period of India, i.e. the period of the late Pre-Cambrian. The Griquatown tillite represents the Ken valley tillite. Thus, the period following it represents igneous formations which came after the Bijawar Traps. In Nama and Transvaal systems we find a large amount of igneous activity just about the same period as that of tillite. There was extensive basic volcanic activity represented by Ongluk volcanics[29]—which attain a thickness upto 5,000 ft. in the Zeerust district of South Africa. The rock consists wholely of fine grained lava of andesitic character. Besides this Dullstroom[30] volcanics also occur in the same formation. The lavas consist of fine grained greenish basic rocks. The volcanic group just occurs above the Griquatown tillite. This group of Ongluk volcanics come just near the tillite horizon. The group consists wholely of volcanic rocks, principally andesitic lavas, the basalt flows of which rest upon the glacial zone or upon some thin hard shales overlying the latter.[31] In other parts of South Africa there is clear evidence that a great volcanic activity occurred just nearabout the glacial zone something corresponding to basic volcanic activity in India just near the Ken valley tillite. Thus these two activities of Nama system in Africa and Cuddapah system in India are more or less contemporaneous. In Africa at the end of Nama system a great deal of folding took place and a great amount of granite was introduced. Probably two or three distinct periods of intrusions occurred during this peirod of folding. In Africa and Madagascar there is a clear evidence of orogenic activity accompanied by the intrusion of plutonic rocks, the age of which is 485 million years, which means this activity took place just at the base of Cambrian. In India also the acid igneous intrusions at the end of Cuddapah and lower Vindhyan period are more or less contemporaneous with the period or orogeny 485 million years old, which is found in Madagascar, East and South Africa. Thus the igneous activity of this period, i.e. from just before the Cambrian to slightly after the beginning of the Cambrian are common to India, Africa and Madagascar. Now we come to Australia. The Sturtian glaciation was a part of world-wide happening and the Ken valley tillite can be correlated with this tillite. Thus the Adelaide system[32] of Australia can be well correlated with the Cuddapah system of India. It is possible that an upper part of this system may also be contemporaneous with the Vindhyans. In the upper part of this system which may be either lower Cambrian or just at the end of Pre-Cambrian a great amount of volcanic activity is found. In Australia the geological evidence suggests an upper Pre-Cambrian age for the Sturtian tillite. It is slightly earlier than the Cambrian period[33] and may represent an age of about 550 million years. Here also the volcanic activity is associated with these glacial beds. There is a large amount of volcanic activity represented particularly in Pilbura gold-field by acid, intermediate and basic lava flows.[34] The Nullagine beds[35] have large amount of contemporaneous basic lavas and pyroclastic rocks together with sills and dykes of dolerite. The presence of volcanic rocks in Upper Adelaide system corresponding partly to the upper part of Cuddapah (Gwalior and Bijawar) are well known in New South Wales and Western Australia. Thus we come to the conclusion that this late Pre-Cambrian igneous activity is well represented in Australia also besides India, Africa, and Madagascar.

DELHI IGNEOUS CYCLE

About the late Pre-Cambrian igneous activity and orogeny we have clear ideas and the igneous activity and orogeny in different parts of India can be correlated. This igneous activity followed by the orogeny, which is about 485 million years old can be well traced, but if we go further back in time it will be difficult to treat India as a whole and we will have to study these activities in isolated areas where they occur.

The period just preceding the Cuddapah in Rajputana is represented by the Delhi system. This Delhi system is highly folded and metamorphosed and at times the metamorphism is even greater than Aravallis. Its general trend is NE-SW. In North Rajputana it becomes N-S. This Delhi system contains a large amount of basic and ultra-basic intrusions[36] and also extrusions consisting of basalts and ultra-basic rocks. These basic intrusions cut the Raialos and are found in Delhi system. They are quite different from the Bijawar or Gwalior Traps and so they must precede the Cuddapah formation and must be post Raialos. The folding of Delhi system was accompanied by the intrusion of granites on a vast scale. The name of Erinpura granite has been given to those granite intrusions, which came at the time of Delhi folding. A large number of pegmatites occur in this formation, some of which contain radio-active minerals. The uranium minerals occur near the village of Bisundni in this system, the age of which has been determined by Prof. Holmes on a very satisfactory basis. The age of this mineral is 735 million years. Thus we find that the Delhi igneous cycle closed about 735 million years ago, i.e. about 300 million years before the end of Cuddapah igneous cycle. It is difficult to give a proper age to the basic rocks followed by ultra-basic rocks of this period, but it is certain that they were later than the Upper Aravalli orogeny. The age of orogeny which preceded the Delhi orogeny is about 950 million years.[38] Thus these basic intrusions must be later than that period and may lie somewhere between 900 and 800 million years or so. Thus it is clear that in Rajputana during the period of sedimentation of Delhis, there was a basic igneous activity followed by ultra-basic rocks about 800 million years ago and that the folding of these Delhi rocks took place just before 735 million years. It is difficult to say as to what was going on in other parts of India, while sedimentation was going on in the arm of the shallow sea now represented by Delhis. Most probably other parts of India were dry land and denudation was going on. We do not know definitely of any other formation in India which can be correlated with the Delhi system with certainty. The difference in age between the Cuddapah cycle and Delhi cycle, the age of first being fixed by Tillite Horizon, and of the second being fixed by the Bisundni Uranite will be about 250 million years. This Delhi system is definitely younger than the uppermost part of Dharwar system as represented by the Iron Ore series in Northern India, as there is no trace of iron ore or manganese in this system. It is difficult to correlate this formation with other parts of Africa, Madagascar, or Australia. But we know that in Madagascar there was a period of orogeny somewhere about 700 million years[39] ago and in Africa also there was a period of orogeny[40] about 600 to 700 million years ago.

DHARWAR IGNEOUS CYCLES

The formations represented by Pre-Delhi system have been included in Archean group. This group is divided into two parts. One is represented by the Dharwar system and the other is represented by gneisses and granites. These divisions were made at a time, when it was supposed that Dharwars lie upon granites and gneisses and are younger than them. But now it has been definitely proved that the various types of granite, which were supposed to be Archean are later than early Dharwars and have been found intruding into them. Thus these two divisions have lost all their significance. The lowest formation of Dharwars is made up of sedimentary rocks and metamorphosed basalts, which have turned into hornblende schists and gneisses. We have not been able to find the primary crust preceding the above sediments yet. Hence the speaker will include under Dharwars all the sedimentary rocks of Pre-Delhi age as well as the igneous rocks associated with them. Even if we assume that the Satpura orogeny marks the end of Dharwar period, the age of which is 955 million years, then too, the whole period between 955 and 3,000 million years amounting to about 2,000 million years will be covered by the system to which the name Dharwar has been given. Thus we see that a single Dharwar period is about four times the period from the Cambrian till now. During these two thousand million years, there have been several igneous activities of Basaltic type, several periods of orogeny, accompanied by granite bosses, and several cycles of sedimentation. The study of this extremely complex formation is very difficult. We have no fossils to guide their age. The rocks are so altered by metamorphism that they have lost all their original characters, so much thrusting and overfolding has taken place, that their true stratigraphical sequence cannot be deciphered. The rocks are found scattered in different regions far from each other. Under these conditions it is no wonder that the correlation of rocks of this system in various parts of India has been very unsatisfactory. There is no data to go by. Here new radio-active methods of age determination of rocks have come to our aid. By means of these methods, we have been able to determine the age of the rocks and minerals and to correlate them with the rocks of similar age in other parts of the world. This seems to be the only satisfactory method for correlating the rocks of different continents and countries. Besides this, there seems to be one geological horizon containing the manganese ores which promises to be of some use in correlating the rocks of Dharwar system in India. According to the views of the speaker, shared by many others also, there is only one period in Dharwars, in which huge amounts of manganiferous sediments were deposited in different parts of India. The conditions for the deposition are so rare, that it is difficult to believe that they were repeated several times. Hence it will not be wrong to assume that there was a definite period when the manganiferous sediments were deposited in different parts of India. This horizon will be of great use in this work of correlation.

A large amount of data[41] has accumulated on the age determination of the rocks of the Dharwar and other systems of India. On the basis of that data we can fix several periods of orogeny during the geological times.

1.	Late Cretaceous and early Tertiary Orogeny	20 million years
2.	Upper Carboniferous Orogeny ...	225 million years
3.	Cuddapah Orogeny	485 million years
4.	Delhi Orogeny	735 million years
5.	Satpura Orogeny	955 million years
6.	Singhbhum-Salem Orogeny ...	1,250 to 1,300 million years
7.	Eastern Ghat Orogeny	1,570 million years
8.	Upper Mysore Dharwar Orogeny ...	2,300 million years

There are two or three more periods of orogeny before this.

After giving this data we will take each Dharwar area separately and assign the age to different formations in it. Mysore Dharwars have been divided in three parts as follows:—

Upper Dharwars.
Middle Dharwars.
Lower Dharwars.

The Lower Dharwars[42] are composed mostly of compact greenstones and schists (basic and intermediate lava flows) followed by acid and intermediate rocks. The Middle Dharwar is mostly composed of metamorphosed sedimentary rocks. Then followed a period of folding accompanied by granitic intrusions.

The Upper Dharwar also begins with conglomerates and is composed mostly of sedimentary rocks. These are followed by the intrusion of Champion gneiss of the Kolar schist belt[43]. After this in age comes the Peninsular gneiss[44] which is followed by the intrusions of Charnockite. Lastly come the intrusions of Closepet granite. Prof. Holmes determined the age[45] of monazite which came from peninsular gneiss. The specimen was sent by Prof. Pichamuthu and the age obtained was about 2,300 million years. This age determination is quite satisfactory. If the age of this Peninsular gneiss be 2,300 million years, the age of Champion gneiss which is older may go upto about 2,500 million years and the age of the volcanic activity of the lowest Dharwar which gave rise to hornblende schists may reach an age upto 2,700 million years. Before Peninsular gneiss there are two periods of granitic intrusions, one in the Upper Dharwar period and the other at the end of Middle Dharwars, and then comes the beds of basic lavas of Lower Dharwar period. Thus the age of this earliest basic igneous activity of Dharwar times may even go down to 3,000 million years and as two periods of igneous activity and orogeny intervene between it and the Peninsular gneiss of 2,300 million years age. These may be of the same age as the earliest Rhodesion Schists, and that this lowest Dharwar formation in Mysore may represent the oldest rocks of India, contemporaneous with schists of Rhodesia, and Tanganyika, having an age of about 3,000[46] million years. After the Peninsular gneiss we have got the Charnockites[47]. The Charnockites have intruded the manganiferous rocks of Kodurite and Khondalite series. The Nellore and Anamapalli pegmatites intruding the Khondalites[48] gave an age of about 1,600 million years. Thus the period of sedimentation of mangenese containing rocks must be more than 1,600 million years. Charnockites are also intruding into this Khondalite and must be of the same age of 1,600 million years or later than that, and the Closepet granite may be still younger representing the Satpura cycles of 955 or even of 735 million years. We do not get any granite, younger than that till we come to Cuddapah period. The monazites and cheralites[49] from Travancore have given an age of about 500 million years and these can be correlated with the Cuddapah orogeny of the northern India, the age of which is about 500 million years. The high quality zircons coming from Ceylon have also been given age[50] between 500—600 million years based upon radio-active data and also belong to Cuddapah orogeny.

The ages of periods of Orogeny in Mysore area seems to be as follows :—

Travancore granite	500 million years
Closepet granite	1,200 or 950 million years
Charnockites	1,600 million years
Peninsular Gneiss	2,300 million years
Champion gneiss	
Basic rocks lowest Dharwar ...	about 3,000 million years.

RAJASTHAN DHARWARS

Another part of Dharwars is represented by the Aravalli system of Rajputana. Here the Erinpura granite has already been assigned an age of 735 million years and therefore the age of all the granites associated with the Aravallis must be greater than 735 million[51] years—and it appears that previous to this there are 3 periods of acid igneous activity in Rajasthan. The Berach-granite is the lowest on which the Aravallis have been deposited. This is supposed to be contemporaneous with the Bundelkhand gneiss which has been considered to be the earliest granite in India. But at present we have studied so many igneous cycles preceding the Delhi cycle that it is very difficult to believe that the acid igneous activity of this Pre-Aravalli period does not fall in with one of those cycles, and the so called Bundelkhand gneiss be contemporaneous with the Champion gneiss or even the Peninsular gneiss. Data of age based on radioactive determination is not available but one factor comes to our aid. In Southern Rajputana, the speaker has studied the Jhabua manganese belt occuring in Madhya Bharat, and came to the conclusion that the manganese ore bed is interbedded with the phyllites of this Aravalli period, probably representing middle Dharwar. This can be traced for a distance of 15 to 20 miles[52] running in N.W.-S.E. direction. The speaker also studied the Sheorajpur Pani belt of manganese ore and has come to the conclusion that most probably these two beds of manganese ore are the two limbs of a syncline pitching towards the east. Beyond Jhabua the northern limb and beyond Pani the southern limb cannot be traced towards the east as they become covered by the Deccan Trap. It is highly probable that these beds are contemporaneous with the manganese ore beds of the Sausar series represented in M.P. Thus we come to the conclusion that these Aravalli beds have been deposited at the same time as the manganiferous beds of Madhya Pradesh and the beds of Khondalite and Gangpur series. Thus the age of phyllites of Aravalli system interbedded with the manganese beds will be same as of Khondalite and be not less than 1,600 million years. Hence the age of Berach granites on which Aravallis rest must be more than 1,600 million years, and the granites may represent a period of orogeny of 2,300 million years or even earlier to that corresponding Champion gneiss. In Rajasthan there are supposed to be two or three igneous activities in pre-Delhi times[53]. These are Berach granite and after that banded gneiss complex. According to Heron and Sharma[54] there is one more pre-Delhi granite which may be of Aravallis age or post Aravalli and pre-Delhi age. This granite might be of an age of Satpura cycle, which is 950 million years or may belong to the 1,200 million years cycle. Thus in Rajputana the cycles will be as follows :—

Malani Rhyolites and Jallor Siwana granite	450 million years
Erinpura Granite	735 million years
Pre-Delhi and Post Aravalli Granite	1,200 or 950 million years
Banded Gneissic Complex and Berach granite	2,300 million years or more.

SINGHBHUM DHARWARS

It appears that after the deposition of manganese ores there was a period when iron ores were deposited on a vast scale and most of the iron ore deposits of India were deposited during this period. This period is later than the deposition of manganese beds and comes immediately after that. The age of magnetite containing beds of Singhbhum and Salem is about 1,200 to 1,350 million years and it is very highly probable that after the orogenic cycle of 1,600 million years these sediments containing iron ore were deposited. Thus in Gangpur, this series starts with manganese containing Gondite beds, the age of which may be about 1,600 million years or more. This is followed by deposition of a large number of sedimentary rocks. After that comes the Iron Ore series with profound unconformity[55]. Here the Iron Ore series may also belong to a period of 1,200 million years. There is no doubt that basic rocks must have been the source of these iron ores and that the manganese contained in these basic rocks must have given rise to manganese ores deposited previously in same way. In Singhbhum, the Iron Ore series lie upon older formations with an unconformity and begins with purple sandstone. In this formation we have got the Dalma Trap[56] followed by intrusions of ultra-basic rocks. At the end came the orogeny accompanied by intrusions of Singhbhum granite. During this period we have a complete igneous cycle beginning with basalt followed by ultra-basic and then acid rocks. If we assume the age of Iron Ore series to be about 1,200 million years, the age of igneous cycle will be less than 1,200 million years and this cycle may well represent with the orogeny the age of which may be about 950 million years. Most probably this cycle represents the last igneous cycle of Dharwar period. The newer dolerite, which intrude Singhbhum belong to Cuddapah period and have an age of about 550 million years. Chota Nagpur granite which extends from Santhal Pargana through Hazaribagh to Palamau and to Ranchi probably belongs to 950 million years cycle i.e. to Satpura orogeny.

BUNDELKHAND GRANITE

As regards the Bundelkhand granite we have no age data based upon radioactivity. But if it be contemporaneous with Berach granite, it must be older than 1,600 million years and must fall in with the age group of 2,300 million years or more. The Kimberlite rocks of Bijawar period have been found intruding into it and so are the Cuddapah granites. In M.P. the Sausar series containing manganese ore beds of about 1,600 million years age have been intruded by granites and gneisses of two periods, which may represent 1,200 and 950 million years cycle.

With the limited data at our disposal we have tried to fit in the igneous rocks and periods of orogeny into definite groups. But the picture is far from clear and much more data has to be accumulated before we can form a clear picture of the Pre-Cambrian history of our country.

Some very interesting conclusions, however, can be drawn from the study of these periods of orogeny accompanied by the periods of igneous intrusions. It is clear that in pre-Cambrian and post Cambrian times, igneous activity had broken out periodically and has been followed by a long period of quietness. The interval between each period of orogeny is about 200 to 300 million years. The only exception to this generalisation is between the orogeny represented by 1,600 and 2,300 million years cycle. Here the gap seems to be double the average interval. It is quite possible that a further detailed study may give us an orogeny of about 2,000 million years age thus bridging the gulf between 1,600 million years and 2,300 million years cycle.

Now we come to the study of Africa. As regards the correlation of formations of Africa and India, we can say with confidence that Nama Transvaal system can be correlated with the Cuddapahs. But before this period, the correlation becomes difficult. What we can say is that the older systems like Rhodesian schists, Eldorado series together with granite intrusions and the Witwatersrand system can be correlated with the Archeans and the Dharwars. But the period represented by these formations is so vast that not much reliance can be placed upon this correlation. What we can say is that gold deposits of Africa in Witwatersrand system may have some relation in time with the gold deposits of the Dharwar system of India in Kolar. Though correlation of rocks between India and Africa in pre-Cambrian times is not possible on geological grounds, yet the correlation on the basis of age determination is feasible. Fortunately for us a very large number of age determinations have been made on African rocks[57] by radiogenetic lead, strontium, argon, helium and ordinary lead methods. The value determined falls into the following groups:—

485 million years, 630 million years, 1,020 million years, 1,200-1,400 million years, 1,650-1,850 million years, about 2,300 million years and greater than 2,900 million years. If we compare these cycles with those in India we find 485 million years cycle represented by the Cuddapah cycle and Lower Vindhyan is also represented in Africa by a cycle of the same age. As regards the Delhi cycle the age in India is 735 million years while the African cycle is 630 million years. The difference is of 100 million years. Looking to the fact that each cycle may be of 50 to 60 million years duration this 100 million years difference is not much and further age determinations may bridge this gap. As regards the third cycle of 1,020 million years in Africa we have a cycle of about 955 million years in India and which differs only by 65 million years. The fourth African cycle represented by 1,200-1,400 million years has a counter-part in India represented by a cycle with an age of 1,200-1,350 million years. The fifth cycle of 1,650-1,850 million years in Africa has its equal in Eastern ghat cycle having an age of about 1,600 million years. As regards 2,000-2,300 million years cycle in Africa, there is no cycle of 2,000 million years age in India but 2,300 million years cycle represented by Peninsular gneiss is well established. Before that there are 2 or 3 more periods or orogeny, the age of which may be 2,000-2,900 million years. It is most likely that the lowest basic volcanic activity of Dharwar may be contemporaneous with the earliest rocks of Rhodesia and may have an age of about 3,000 million years. In India we have got six well recognised pre-Cambrian cycles and it is likely, on geological grounds, that two more igneous cycles preceded them, thus making up a total of eight igneous cycles, and two more follow in post Cambrian times. For Madagascar[58] the relation is also the same except that instead of 730 million years cycle we have got a cycle of about 650 million years.

This similarity in age in these two continents is not merely a matter of chance but clearly proves that these two continents have suffered the same fate in geological times, strongly suggesting that they were much nearer to each other in the past than what they are now. It is not possible in this short address to deal with the directions or orogeny in these continents.

In Australia the igneous cycles which ended with the upper pre-Cambrian are well known. Here we find a lower Cambrian period igneous activity[51] and that the orogeny came about the Middle Cambrians when acid granites were intruded. This activity is more or less contemporaneous with Cuddapah cycle in India, though the basic igneous activity might have begun on a slightly later date, about 500 million years. Thus the Upper pre-Cambrian and Lower Cambrian activity is common to Africa, India and Australia. As regards the older cycles, the data is not available. The period before the Adelaide system has been referred to Lower and Middle pre-Cambrian. The data for age in Australia is not as abundant as in Africa but still we will give here what is available. The granite of Norman-Vills and Olary in South Australia give an age of 990 million years and this granite has been placed in Middle pre-Cambrian. This 990 million years age corresponds to the age of Satpura orogeny, the age of which is about 935 million years. The pegmatites of Pilbara Gold-field give an age of 1,280 million years. This corresponds to 1,200 million years cycle of India and Africa. Mount Isa in Queensland gives an age of 1,200 million years. The age of galena from Gold reef from Kalgoorlie system is 2,760 million years. In Kalgoorlie system, there are plutonic intrusions of at least two epochs during Lower and Middle pre-Cambrian times. Besides this the granite has also invaded and metamorphosed the Yilgarn series as well as the Mosquito series of Pilbara area. Thus the following cycles are clear :—

450 to 500 million years
990 million years
1,280 million years
2,760 million years

Between 2,760 and 1,280 million years, two or three more periods of orogeny accompanied by granite intrusion are present. Most probably these are represented by 2,000 and 1,600 million years cycles. So here also, whatever data is present confirms the view that the igneous cycles and periods of orogeny in Australia were more or less contemporaneous with the periods of similar igneous activities and orogeny of Africa and India.

Thus the study of Australia also proves that the periods of orogenies have been almost contemporaneous, and though here and there some links are missing, we find that generally they come with an interval of 200 to 300 million years.

Much data is not available about South America and it is not quite reliable. But there, too, the cycles of 500 million years and 1,200 million years are well marked. Thus we find that in all the countries forming the old Gondwanaland consisting of India, Africa, Madagascar, Australia and South America, the major periods of igneous activity and orogeny are almost the same. Surely this cannot be a coincident and it strongly supports the view that during the whole of Gondwanaland existence lying in Southern hemisphere, the periods of stress and strain were almost the same.

We have tried to trace the history of igneous activities and periods of orogenesis from early times. Much more work remains to be done before we can place this correlation, based upon age determination, on a very satisfactory basis. The new method of determining the age of the rocks and minerals by Potassium-Argon method offers a great scope for the determination of the age of feldspars associated with different periods of activities in India. But unfortunately there is not a single centre in India where such kind of work can be carried out. In U.S.S.R. a special institute exists for this kind of work and more than 800 determinations have been made. In Toronto in Canada, this Potassium-Argon work is being carried out. In M.I.T. in U.S.A. they have got laboratory for helium determinations under Prof. Hurley. Prof. Ahrens has been carrying out the work on rubidium, strontium method, first in M.I.T. in

U.S.A., then at Oxford, England, now in South Africa. Prof. Nier in Minnesota is carrying out the work of isotopic determinations of lead. But in India, though a very large amount of money is being spent upon research work, still the results have been very disappointing in this direction. Inspite of the personnel of Geological Survey being increased several times and inspite of the creation of the Atomic Energy Commission with huge staff, as well as other departments, we have not been able to use most upto-date methods and are following the old ones. We have got excellent personnel which is able to do the highest quality of work in Europe and America, but when these persons return to India, due to circumstances beyond their control, they are not able to do much. It is the duty of the older generation which is at the helm of the affairs to give chance to the younger generation and to provide them with opportunity and encouragement to carry on the work, which they did in U.S.A. or in Europe. At the present time there is no dearth of money, but personnel and proper equipment are needed. The speaker hopes that in some place in India, either it be in the Universities or in Geological Survey or in Atomic Energy Commission, a centre for carrying out work on age determination by all possible methods will be established and that the scholars, from different parts of India will be given opportunities and facilities to carry out their research work in that laboratory, either it be in the control of Geological Survey or Atomic Energy Commission or Bureau of Mines or Oil and Gas Commission or Universities.

At the end I may say that the geological work in India is being carried out by four agencies without proper co-ordination. In order to get the best results with the least cost, it is essential that all the four deparments, that is, G.S.I., I.B.M., A.E.C., O.N.G., must be under one minister, with an advisory council consisting of Heads of all the four departments. This council should draw the plan for mineral development and bring about close co-ordination between the work of all the four agencies and that there must also be better co-operation between the Universities and the Government departments. It should be possible for the University Professors to be deputed to G.S.I. for two or three years, and G.S.I. staff to be deputed to the Universities to serve as Professors. Thus the University Professors who are to train new generation will be kept up-to-date in their field work and will not become merely arm chair geologists, while the members of staff of G.S.I. will not only be a field geologist or administrative bosses, but will be kept in touch with the young budding geologists and also with the progress of science as a whole, and will not lose the spirit of research in pure science, on which every advancement of applied science depends. At present it is easy for Indian Professors of Geology to go and work with the Canadian or U.S. Geological Survey, but it becomes more difficult for them to carry out with the Indian Geological Survey or Geophysical Survey parties. The result is that we University men know more of the work being carried out in U.S.A. and Canada than in our own country.

A teacher of Geology cannot be up-to-date, unless he is kept in practical touch with all the research work being carried out in his own country, and thus the training of our younger generation entrusted to the Universities will suffer, unless the Professors are kept up-to-date. The speaker hopes that in the third five-year plan, with our limited resources, it will be possible to co-ordinate the work of all the Departments engaged in tracing the history of the earth and winning and utilising all the mineral products which our mother earth holds. There will also be better co-ordination with the Universities. It will be desirable to create a mineral development research council, on the lines of agricultural research council, consisting of the representatives of all interests and that this council will advise the Government on all the ways and means of mineral development.

In the end I have to thank you all for giving me an opportunity for placing my views before you, and I hope that something will be done to remove the deficiencies referred to before.

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SECTION OF BOTANY

President :—Prof S. K. Pandé, D. Sc., F.N.I.,

PRESIDENTIAL ADDRESS

THE ANTHOCEROTALES, SOME ASPECTS OF THEIR SYSTEMATICS AND MORPHOLOGY

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I. Introduction

I deeply appreciate the great honour my friends have done me in electing me to preside over the deliberations of the Botany Section of the 47th Session of the Indian Science Congress. It is not merely a great honour, it is indeed a rare privilege to have an opportunity to address such a galaxy of distinguished botanists who have assembled here, at this stately city of Bombay, from far off places in the country as well as from some of the most scientifically advanced nations of the world. I take this as a tribute to the branch of botany—Bryology—to which I have been devoted, rather than to any work that I might have done.

Ladies and gentlemen, this kind gesture from my friends is an indication of the unparallelled devotion of the Indian Botanists to the time honoured tradition of the scientists, "Science for its own sake", a case which, as quoted by Dr. A. L. Mudaliar (1959) in his Presidential Address before the Indian Science Congress Association last year at Delhi, has been so ably advocated by one of the most eminent scientists and scholars, Sir Edward Appleton.

Addressing the British Association for the advancement of Science in 1953 (see Mudaliar 1.c.) Sir Edward states :—

"I have long held the belief that the cost of scientific research is the price we pay for our industrial progress. But we should be misleading the public as well as ourselves if we based our case for the general support of the pursuit of science for its utilitarian aspects alone. I know we can claim many discoveries in pure science, which in their time had obviously no practical import, have later proved to be foundation of major improvements in every material civilization. But even that is an argument of profit and loss and to my mind does not bring us entirely to the heart of the matter. I should like to go back beyond the achievements to the example of the scientist—be he amateur or professional—who is impelled by a passionate desire to explore and to understand. That is what I mean by Science for its own sake when knowledge and insight are sufficient reward in themselves".

Friends, I must point out at the very outset that it is generally held that the liverworts are of practically no use to the common man and in the present set up of the atomic age with the index of the human population advancing in arithmetical progression challenging the nations to face the immediate problems of food shortage and armaments the bryologist has hardly a place in the orbit of the scientists who are likely to contribute something towards the solution of any such problems or towards any material advancement of the country or the welfare of the nations. It is thus, but natural that neither the State nor any official or private organization or society should ordinarily be willing to finance researches in this unprofitable field nor is there much chance of the demand for persons especially qualified in this branch. It is therefore, not difficult to understand that Bryology, like some other branches of pure Botany, has but little attraction for research workers except those who firmly believe with Sir Edward that 'Knowledge and insight are sufficient reward in themselves'.

II. The Topic

More than 40 years back an eminent bryologist and one of the foremost makers of Indian Botany, my own revered "Guru", the late Professor Shiv Ram Kaṣhyap (1919), addressing from this chair, at this very city of Bombay, discussed at some length, 'Relationship of the liverworts especially in the light of some recently described Himalayan forms'. But it has been rather unfortunate, as pointed out by Fulford (1948), in her critical discussion, 'Recent interpretations of the relationships of the Hepaticae', that this excellent thesis, so ably put forth by Kashyap, has failed to draw adequate attention of the botanists outside India. In my address this morning I propose to offer a few remarks on the taxonomy and morphology of the Anthocerotales or the 'horn liverworts' a small group of the Archegoniatae which, according to the commonly accepted arrangement constitutes one of the four orders of Liverworts, one of the two main phyla of the Bryophyta, although some eminent bryologists (Howe, 1898 ; Campbell, 1905) have given it the rank of a class co-ordinate with the rest of the Liverworts on the one hand and the Musci on the other.

III. Historical Review

The early systematists recognized only three genera among the Anthocerotales viz.,

1. *Anthoceros* L.
2. *Dendroceros* Ness.

and 3. *Notothylas* Sull.

The composite nature of the largest genus *Anthoceros* L. was recognized since the time of Gottsche, who, as early as 1858 (see Schiffner, 1909, p. 140), recognized, on the basis of the capsule-wall and elaters, three sections as defined below :—

Section 1. Pseudoelateren bestehen aus ganz Kurzen Zellen ohne spiral Band. Kapsel mit Spaltöffnungen. (Hierher gehören die beiden gennanten europaischen Arten).

Section 2. Pseudoelateren aus langen Zellen bestehend, ohne spiral Band, Kapsel mit Spaltöffnungen.

Section 3. Sterile zellen als Elateren entwickelt. Diese bestehen aus 3-4 langen zellen mit einem breiten spiral Band, welches sich ununterbrochen durch die ganzen Elater hindurch zieht. Kapsel ohne Spaltöffnungen. Hierher. z. B. *A. vincentianus* L. et L.

English Version :—

Section 1. Pseudoelaters consist of short entire cells without spiral band. Capsule with stomata. (To this section belong both the named European species).

Section 2. Pseudoelaters consist of long cells without spiral band. Capsule with stomata.

Section 3. Sterile cells developed as elaters. These consist of 3-4 long cells with one broad spiral band, which stretches uninterrupted through the entire elater. Capsule without stomata, e.g., *A. vincentianus* L. et. L.

Later on, mainly on the basis of these differences three independent genera were segregated. Thus Campbell (1907) separated from *Anthoceros* L. *all those species, which lack stomata from the capsule-wall and possess elaters with a spiral band of thickening, in an independent genus Megaceros* Campbell. Similarly a few years later Stephani (1917) established a new genus *Aspiromitus* St. to include all the species of *Anthoceros* L. which possess long simple septate elaters (*Elateres longi, simplices, septati*). Thus five genera were recognized in the *Anthocerotales* :—

1. *Notothylas* Sull.
2. *Dendroceros* Nees.
3. *Anthoceros* L.
4. *Megaceros* Campbell

and 5. *Aspiromitus* St.

It may be stated here that Stephani's genus never received the universal acceptance of the bryologists.

Discussing this issue D. H. Campbell (1940, p. 56) states: "The largest genus, *Anthoceros*, has been subdivided but the basis for doing so is not very clear. Stephani separates 55 species to form the genus *Aspiromitus*. Some of these, e.g., *Aspiromitus vesiculosus*, have an elongated thallus with marginal leaf-like lobes and elaters longer than in most species of *Anthoceros* ; but the differences seem insufficiently constant to warrant the establishment of a new genus".

A few years earlier Bartlett (1928), referring to the same liverwort, possibly from the same specimen, recognized two forms in *Anthoceros vesiculosus*, viz., (1) *A. vesiculosus* (Maui) with long thick-walled elaters (Bartlett 1.c. fig. 9A) and (2) *A. vesiculosus* (Hilo) with short fragile elaters (Bartlett, 1.c. fig. 9B). This obviously would explain the differences to which Campbell referred.

Prof. Goebel (1930), while accepting the genus *Aspiromitus,* did not agree with Stephani in maintaining the elater as a suitable character for generic segregation. He distinguished the two genera on the basis of their antheridia. In this connection he (Goebel, l.c.) states that in *Aspiromitus* the antheridium (Goebel l.c. fig. 30) is an oblong, elongated or club-shaped structure borne on a long stalk with the wall cells arranged in distinct tiers or storeys, the topmost functioning as an apical cap or operculum (Goebel, l.c. fig. 30) ; while in *Anthoceros,* it is plump and spherical and the wall cells are not arranged in tiers or storeys nor is there any special mechanism for the liberation of the sperms.

Some years later Rink (1935, p. 96), from a study of *Aspiromitus samplocensis* Burgeff, a black spored species of *Anthoceros* L., and *Anthoceros tjipanasanus* Burgeff, a yellow spored species, described another distinctive feature for these plants, the difference being mainly in their antheridial chambers. In *Aspiromitus,* according to Rink (l.c.), the antheridial chamber is in the form of a raised pointed cone which opens from above and shows a sort of neck (Rink, l.c. fig. 1). If mechanically not destroyed this cone remains until the antheridia in the chamber have matured and discharged their function. The antheridial chamber thus shows a cratershaped structure which is preserved till the decay of the thallus. In *Anthoceros,* on the other hand, the roof of the antheridial chamber shows only a hump-like flat arch the upper part of which gelatinizes later and exposes the antheridia directly.

IV. Observations and Discussion

It will be evident from the above that Goebel (l.c.) as well as Rink (l.c.) discovered some excellent diagnostic characters in the taxonomy of the Anthocerotales but it is rather unfortunate that neither they nor, as far as I know, any one else, examined critically the several genera of the Anthocerotales, not even the old complex *Anthoceros* L. and its subsequent segregates, in the light of the above observations, till only quite recently when Proskauer (1948, 1948a, 1951, 1953), through his valuable contributions, succeeded in clarifying some of the anomalies in the taxonomy of the group. From his detailed study Proskauer has shown that the elongated, oblong or cylindrical antheridium, borne on a long stalk with the wall cells arranged in regular tiers, the topmost functioning as an apical cap or operculum, associated by Goebel (l.c.) with *Aspiromitus,* is also found in *Anthoceros* and is in fact a distinctive feature of the latter while the spherical or globular antheridium, with the wall cells irregularly disposed, assigned by Goebel (l.c.) to *Anthoceros* L., is now known to be a characteristic feature of *Phaeoceros* Prosk., the yellow spored section of *Anthoceros* L. The evidence at present available shows that the *Phaeoceros* type of antheridium is also found in *Megaceros* Campbell.

The androecial features described by Rink (l.c.) for the two members of the Anthocerotaceae are also of great diagnostic value. In *Anthoceros tjipanasanus* Burgeff, a yellow spored species of *Anthoceros* L. which, in the light of the researches by Proskauer (1948, 1951), should now be referred to *Phaeoceros* Prosk., Rink (l.c.) states that the antheridial chamber shows on the surface only a hump-shaped flat arch the upper part of which gelatinizes later and exposes the antheridia directly, while in *Aspiromitus samplocensis* Burgeff, which, in the light of recent researches (Prosk. l.c.) is *Anthoceros samplocensis,* the antheridial chamber is in the form of a raised pointed cone which opens to the exterior from above and shows a sort of neck. If mechanically not destroyed this cone remains until all the antheridia in the chamber have matured and discharged their function. The antheridium thus shows a crater-shaped structure which is preserved until the decay of the thallus.

Discussing *Aspiromitus* St. Proskauer (1948, p. 262) observes, "Rink (1935), following Goebel, considers the antheridia, in which the cells of the wall are arranged in tiers, to afford the best criterion. On the strength of the single species studied by him, he gives as an additional feature the presence of a neck at the aperture of the antheridial chambers. Such a neck is sometimes present and sometimes absent in all the British species of *Anthoceros* and is, therefore, of no systematic importance."

The antheridial chamber :

An examination of some of the species of *Anthoceros* (L.) Prosk. growing in India, i.e., (1) *A. mangaloreus* St., (2) *A. punctatus* L., (3) *A. erectus* Kash., (4) *A. crispulus* (Mont.) Douin, (5) *A. amboiensis* Schffn., (6) *A.* cf. *gemmulosus* (Hattori) Pande, (7) *A. physocladus* Schiffn. et Pande MS and (8) *Anthoceros* sp. from Pachmarhi, shows that the antheridial chambers in all these species are more or less of the type described by Rink (l.c.) for *A. samplocensis* Burgeff. In all these species the antheridial chambers are very conspicuous, being more or less always in the form of raised pointed cones or pustules (Plate I, figs. 1-3 ; Plate II, fig. 7 ; Text fig. 8) opening from above by a definite minute central pore and, if mechanically not destroyed, these will retain their form until all the antheridia in the chamber have matured and discharged their function (Plate I, fig. 5). The antheridial chamber in all the species of *Anthoceros* (L.) Prosk. shows more or less the same type of structure as has been described above. The neck-like structure, noted by Rink (l.c.) for the antheridial chamber of *A. samplocensis,* which according to Proskauer (l.c.) 'is sometimes present and sometimes absent in all the species of *Anthoceros*' and, if it is something other than a frill along the antheridial pore, has not been observed by me in any of the species referred to above. May be, it is a special feature of *A. samplocensis* Burgeff or a structure of very short duration.

In the yellow-spored species of *Anthoceros* L., which now, according to the findings of Proskauer (1951), should be referred to *Phaeoceros* Prosk., and of which Rink (l.c.) studied *A. tjipanasanus* Burgeff, the antheridial chamber is in the form of a hump-shaped flat arch which gelatinizes later and exposes the antheridia directly. In the species of *Phaeoceros* Prosk. occurring in India, i.e., (1) *P. laevis* L., (2) *P. communis* St. (may be only a form of *P. laevis*), (3) *P. himalayensis* Kash., and (4) *Phaeoceros* sp. with long elaters from Kandy, Ceylon, the antheridial chambers are always of the type described by Rink (l.c.) for *A. tjipanasanus* Burgeff. There is hardly any doubt that the androecial characters of the two genera are their diagnostic features. As has already been noted (see Goebel l.c. and Rink l.c.) another distinguished feature of these two genera is their antheridium.

Thus, the characters of the male apparatus are the most reliable diagnostic features of the two genera. However, it must be stated here that in these features *Megaceros* Campbell is also similar to *Phaeoceros* Prosk. and these features are not only distinctive of genera but of larger units perhaps of families or sub-families.

Secondary antheridia and development of meristematic cushion :

There is yet another character of the male apparatus of the Anthocerotales which, according to our findings, appears to be of some systematic value and to this I should like to refer here. It relates to the proliferation of the secondary antheridia.

It is a well known fact that in several genera of the Anthocerotales additional antheridia are produced for a longer or shorter period. In some species of *Anthoceros* (L.) Prosk., i.e., *A. mangalareus* St., *Anthoceros* cf. *gemmulosus* (Hattori) Pandé (Bharadwaj, 1958), *A. harrisanus* St. (Pandé and Bharadwaj, 1949), the capacity to produce such antheridia is almost unlimited and it is not unusual to find numerous antheridia in the antheridial chambers. In this connection it has generally been stated by most authors (Campbell, 1940 ; Proskauer, 1951) that the secondary antheridia develop by budding from the stalk of the primary antheridia, but the details of the process, as far as I am aware, were not described till quite recently when Bharadwaj (1958) described it for *Anthoceros* cf. *gemmulosus* (Hatt.) Pandé. This has been confirmed for a few other species, i.e., *A. mangaloreus, A. amboinensis* Schiffn., etc., (Bharadwaj, 1952). In every case the secondary antheridia develop in a very precise manner, regularly from the primary basal cells lying below the stalk of the primary antheridia. The developmental pattern is always the same as has been described by Bharadwaj for *Anthoceros* cf. *gemmulosus* (Hattori) Pandé. The primary basal cells remain active for almost an indefinite period producing marginally a meristematic cushion-like structure bearing antheridia (Bharadwaj l.c. fig. 21). This would account for the development of an indefinite number of antheridia in the antheridial chambers of such species. The few species of *Anthoceros* that have been studied by me and my students all conform to the above type and it is very likely that the process is the same for all the species of *Anthoceros* and if confirmed this would provide yet another distinctive feature of this genus. It would thus be worthwhile to examine from this view point several more species of this genus as well as of other genera where secondary antheridia develop by budding.

If now one were to reflect for a few moments over the situation that would follow as a result of this capacity of antheridial proliferation for an indefinite period one would naturally be led to the conclusion that, for an efficient and definite discharge of the function and protection of the antheridia, without hindering their function of sperm dissemination when these are formed successively, it would be necessary that the roof of the antheridial chamber is more or less stable and rigid. The type of the antheridial chamber described above for the several species of *Anthoceros* is well suited for the purpose and provides an excellent arrangement for the discharge of these functions. Obviously, a firm roof with a small aperture in the centre of the antheridial chamber would serve this purpose efficiently (Plate I, figs. 1-3 and 5, 6 ; Text fig. 8).

Liberation of sperms :

A few years ago, in the course of my tour of the Western Ghats, I had an occasion to examine in the field at Agumbe under a microscope the living specimens of the male thalli of *A. mangaloreus* St. It was intriguing to observe the way the antheridia are arranged in the chamber. One could easily watch some of these golden-yellow or orange coloured bodies, when mature, swaying gracefully on their tall slender stalks inside the chamber. Ultimately they come to occupy the centre of the chamber. The entire set up is such that one would hardly doubt that ultimately the fully ripe antheridia, with their elongating stalks, are sure to find their way into the aperture in the centre of the antheridial roof. Once the tip of the antheridium comes in the narrow opening of the roof it would undoubtedly press against the wall and the turgid apex would thus burst and set the sperms free which are ready to be shot some distance like water spurted from a syringe. It is also quite likely that sperm liberation is further facilitated by the impact of falling rain drops. Once the antheridia have dehisced and thrown out the sperms they lose their turgity and collapse. Meanwhile, the antheridia that have now matured converge towards the centre of the chamber. This process is repeated to almost an indefinite period and the sperms are made available to the archegonia as these mature. This obviously explains the production of a luxuriant crop of sporophytes in *Anthoceros* (L.) Prosk.

In the yellow spored section of *Anthoceros* (L.) i.e., *Phaeoceros* Prosk. the configuration of the male apparatus is entirely different. In the first place the roof of the antheridial chamber gelatinizes as the anthediria mature (Plate I, fig. 4). Under such conditions it is hardly likely that the sperms would be available for a long time. Very often budding of the antheridia is also only for a limited period and all the antheridia probably mature simultaneously and discharge their sperms at the same time except those few that arise from budding. There is also obviously no special mechanism for the dehiscence of the antheridia and the sperms are probably set free by the irregular breaking of the antheridial wall. Possibly also all the sperms, when liberated, would come to lie in the antheridial chamber and would apparently be dispersed by the rain drops as they strike these chambers. It is not unlikely that the wide open chambers, with the mass of sperms lying within, would be an advantage for the plant. Thus, the antheridial apparatus as well as the mode of sperm liberation and dispersal are much simpler and less efficient as compared to *Anthoceros* (L.) Prosk. This may account for a comparatively poorer crop of sporophytes often produced in *Phaeoceros* Prosk.

In *Megaceros* Campbell where, as a rule, only one antheridium develops in each antheridial chamber, the process of sperm liberation and dispersal is quite likely of the same type as described above for *Phaeoceros* Prosk.

Our knowledge of the other genera of the group, i.e., *Notothylas* Sull. and *Dendroceros* Nees is not so complete in this respect. From what little I have seen in the case of *Notothylas* I am inclined to infer that the process is precisely the same as in *Phaeoceros* Prosk.

The thallus :

Taking into account the thallus of the Anthocerotales (*Anthoceros, Phaeoceros, Megaceros* and *Notothylas*) there is hardly any doubt that the greatest complexity of structure and differentiation is met with in *Anthoceros* (L.) Prosk. In all the species of this genus there are large mucilage chambers. In some cases the adjacent chambers are separated by very thin septa (Text fig. 12). Similar chambers extend in involucres as well.

In *Phaeoceros* (Plate I, fig. 4 ; Text fig. 13), *Notothylas* and *Megaceros* the thallus is compact and there are no mucilage chambers. The mucilage lies in intercellular spaces. *Dendroceros* stands by itself. It shows leaf-like lobing of the gametophyte, otherwise the organization of the thallus and the axis is on the same principle as in *Anthoceros* and *Phaeoceros.*

The sporophyte :

The sporophyte of the Anthocerotales has been a subject of numerous investigations (Campbell, 1907 ; Bartlett, 1928 ; Pandé, 1932, 1934 ; Proskauer, 1948 ; Bharadwaj, 1950, 1958) and it has also provided some material for speculation in connection with the origin of the vascular plants, especially ever since the time of the well known theory put forth by Prof. Bower (1908) for the origin of a land flora. Without entering into the merits or demerits of the view put forth by Bower (l.c.) and others it must be admitted that among the living non-vascular plants the nearest approach to the sporophyte of the undoubted living vascular plants is to be found among the Anthocerotales. With the advancement in our knowledge of the Rhynie chert flora the group has assumed great importance.

Taking into account the various genera of the Anthocerotales we find that the most complex sporophyte is in the genus *Anthoceros* (L.) Prosk. In some of the species of one of its sections, I have noticed very massive and long sporophytes, the centre being occupied by a massive columella (Plate II, fig. 8). In a transverse section the columella consists of about 64 rows of cells. The wall is also comparatively thicker and has chloroplasts in the inner cells ; the outermost layer, forming the epidermis, possesses stomata. In such species the meristematic seta continues its activity for a long time. The foot is very conspicuous and its lowermost layer, which is in contact with the gametophyte, consists of large prismatic cells (Plate II, fig. 9) which undoubtedly have an absorptive role.

The 4-celled pseudoelater in *Anthoceros* is a perfect elater in its morphology as well as function and corresponds to a spore-tetrad. The archesporial cells destined to form elaters divide twice like the spore mother cells but the four cells are held together (Bharadwaj, 1958). The pseudoelaters in *Anthoceros* as studied in *A. crispulus* (Bharadwaj, 1950 ; Test fig. 3) and *A.* cf. *gemmulosus* (Bharadwaj, 1958 ; Text fig. 2) are normally four-celled, with wide lumen and thin, collapsible walls. In *A. physocladus* Schffn. et Pande MS elaters are long and have perfectly thick walls having hardly any lumen (Text fig. 1). In *Phaeoceros communis* (Text fig. 4), *Phaeoceros* cf. *maraguensis* St. (Text fig. 5, Plate II, fig. 12) studied by Bharadwaj (1952 MS) and *Phaeoceros* sp. from Almora (Text fig. 6) the structure as well as the size of pseudoelaters are closely comparable to those in *A. crispulus* and *A.* cf. *gemmulosus* (Plate II, fig. 10). At the same time the thickening in the elaters of *A. physocladus* is very pronounced and the elater, as far as one can see, corresponds to the elater of *Megaceros* (Text fig. 7), the only difference being that in the latter the thickening is in the form of a spiral while in the former it is uniformly distributed. In *Notothylas* the pseudoelaters, apart from being very small, have irregular spiral bands of thickening on the walls.

V. CONCLUDING RRMARKS

If we now consider the genera *Notothylas, Phaeoceros, Megaceros* and *Anthoceros,* in the light of the morphological details and structure of the thallus (Text figs. 12 and 13) antheridial chamber (Text figs. 8 and 9), antheridia (Text figs. 8A and 9A) antheridial organisation, the development of the secondary antheridia, the structure of the elaters, spore pattern and colour and the form of the foot (Text figs. 10 and 11) we find that the genera fall into 3 groups, i.e., I. *Notothylas*, II. *Phaeoceros* and *Megaceros*, III. *Anthoceros* (L.) Prosk. Müller (1939) had earlier proposed the segregation of *Notothylas* into a distinct family of its own, Notothylaceae, leaving *Megaceros* Campb. and *Anthoceros* L. (*Anthoceros* (L.) Prosk. and *Phaeoceros* Prosk.) in the family Anthocerotaceae.

While agreeing with Müller (l.c.) in his proposal to segregate *Notothylas* into a separate family it is further felt that, in the light of recent advances in the morphology of the Anthocerotales and the facts presented here, *Phaeoceros* and *Megaceros* are more closely related and form a natural group separate from *Anthoceros* (L.) Prosk. Apparently each of the two groups should be raised to an independent family rank co-ordinate with Notothylaceae Müll.

It may further be added that among the species of *Anthoceros* (L.) Prosk. there is a section of the species, i.e., *A. physocladus* Schffn. (Text fig. 1), *A. mangaloreus* St. and a few others which constantly possess uniformly thick-walled vermiform elaters (Plate II, fig. 11 and Text fig. 1). Obviously these occupy the same position with respect to other black-spored species of *Anthoceros* as the genus *Megaceros* Campbell with respect to *Phaeoceros* Prosk. It would be worthwhile to investigate the full morphological details of as many species of this section of *Anthoceros* as possible.

I would further like to add that while the Anthocerotales have generally been included among the liverworts as an order of the latter placed on the same level as the Marchantiales, Jungermanniales and Sphaerocarpales, it has also been advocated to rank them as a class co-ordinate with the rest of the Hepaticae on the one hand and Musci on the other (Howe, 1898 and Campbell, 1905 and 1918). One of the main arguments advocated in favour of the latter view has been the difference in the origin of the archesporium in the Anthocerotales and the rest of the liverworts. As I have shown elsewhere (Pande, 1934), such a distinction can no longer be maintained as in the genus *Notothylas* the differentiation of the archesporium follows both of these patterns. In *N. indica* Kash. it originates from the inner aphithecium, as in all other genera of the Anthocerotales, while in *N. levieri* Schffn. it arises from the endothecium as in the rest of the liverworts. My investigations on *Notothylas* have convinced me that this is a constant distinctive feature of the columellate and the non-columellate species of *Notothylas*. The investigation of the other species of *Notothylas*, lacking columella, is awaited with much interest. I personally feel that the Anthocerotales comprise only an order of the Hepaticae co-ordinate with the Marchantiales, Jungermanniales, etc.

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(Text figs. 1-3)

(*Elaters*)

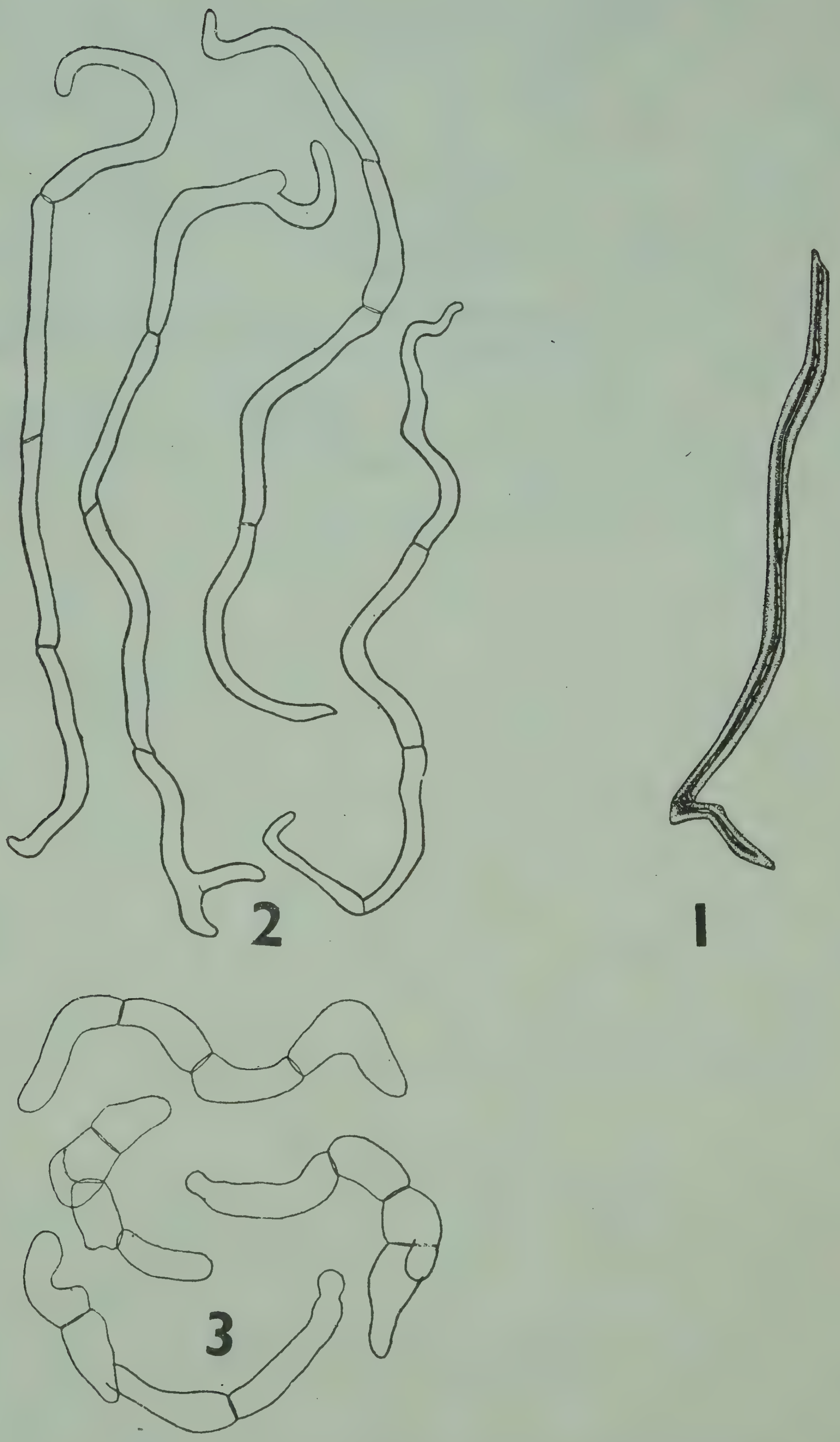


Fig. 1. *Anthoceros physocladus*. ×300. Fig. 2. *A gemmulosus*. ×250. Fig. 3 *A. crispulus*. ×300.

(Test figs. 4-7)

(*Elaters*)

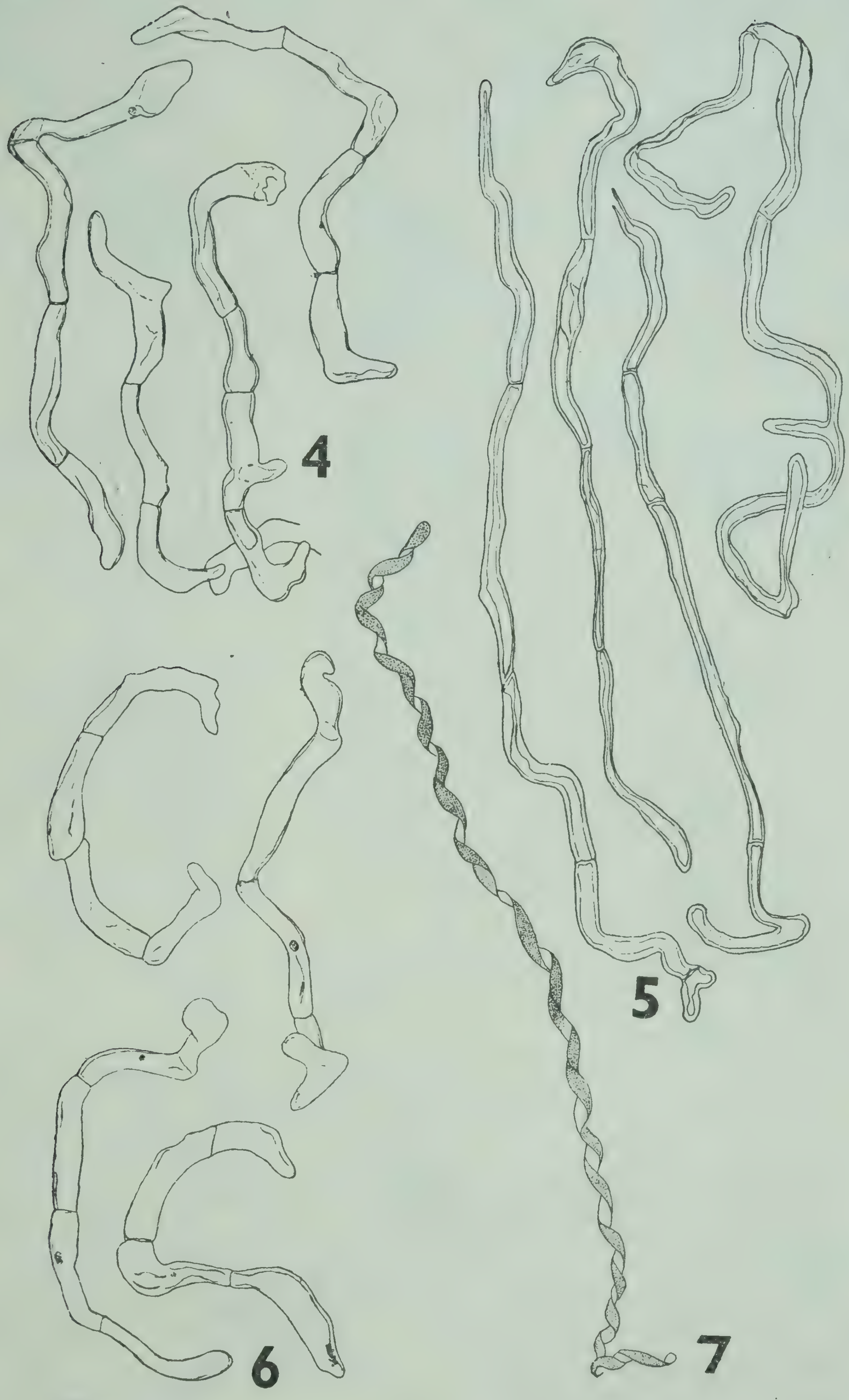
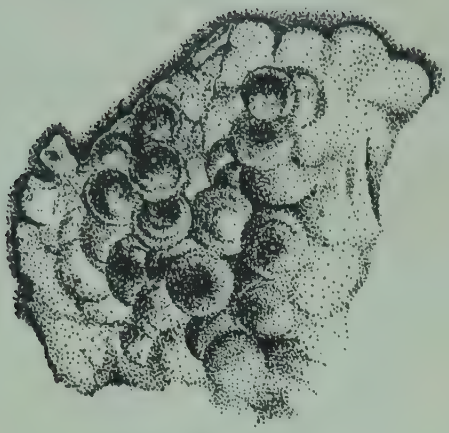


Fig. 4. *Phaeoceros communis*. × 400. Fig. 5. *Phaeoceris* sp. cf. *maraguensis* from Kandy, Ceylon. × 250. Fig. 6. *Phaeoceros* sp. from Almorah. × 250. Fig. 7. *Megaceros stahlii* × 300.



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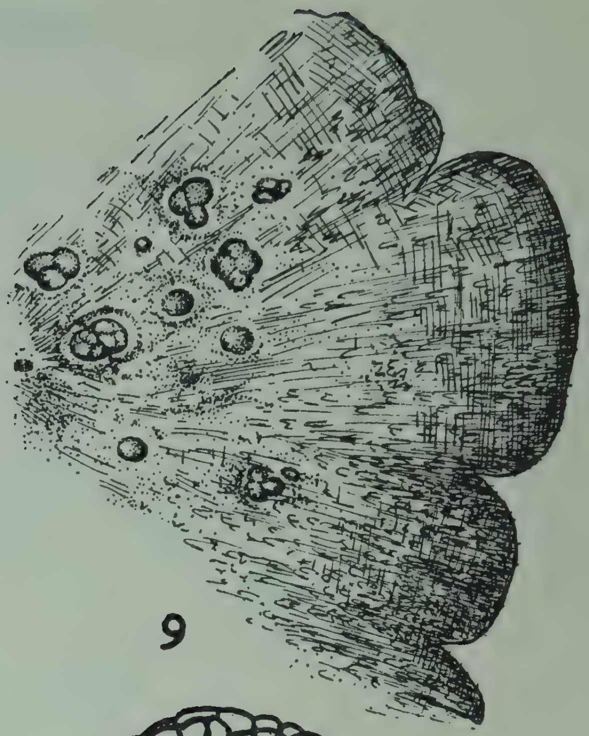

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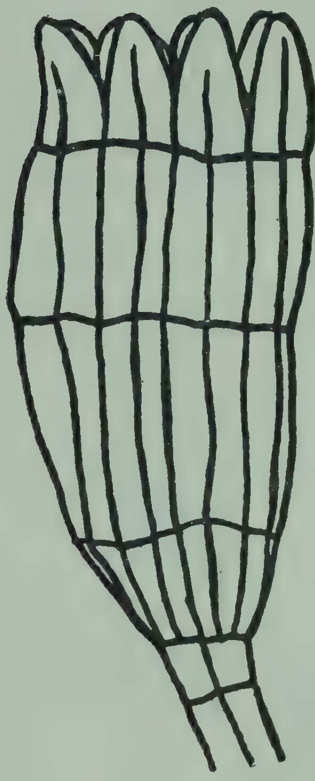

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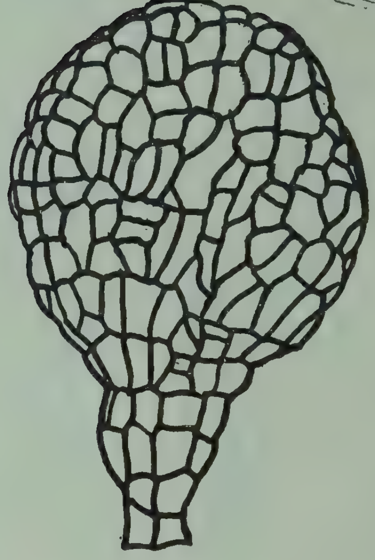

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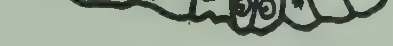

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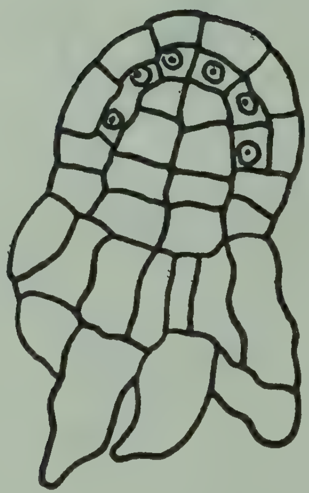

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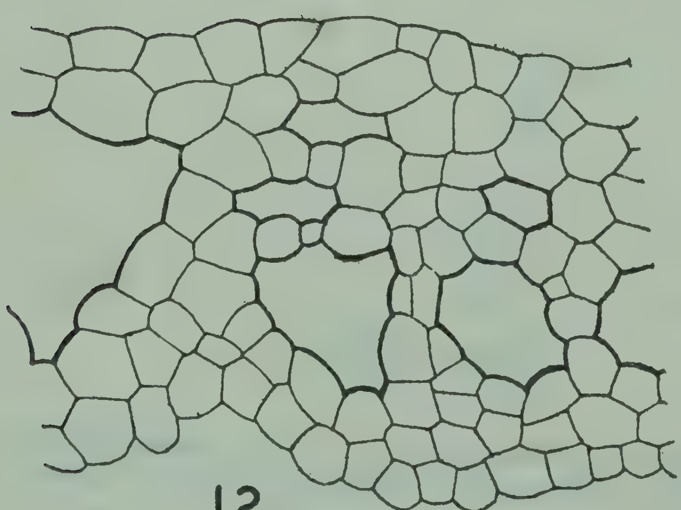

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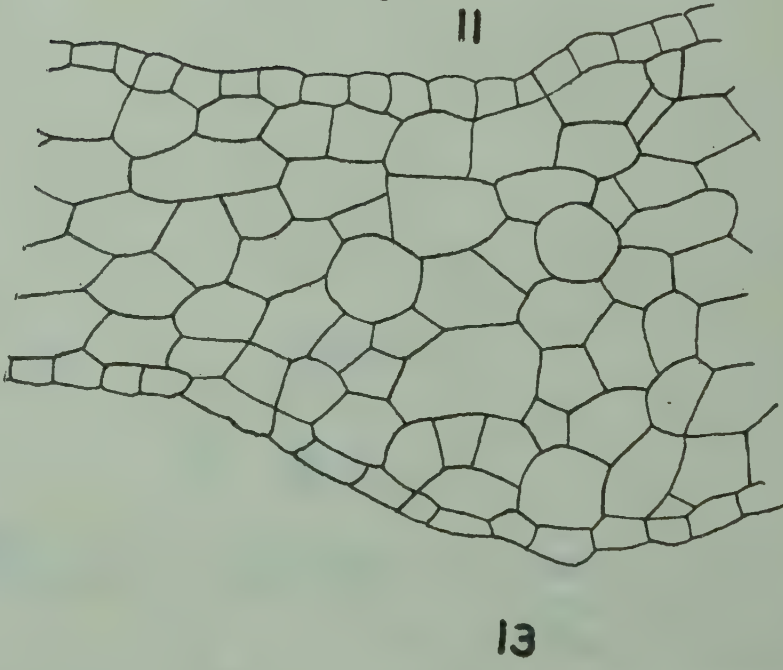

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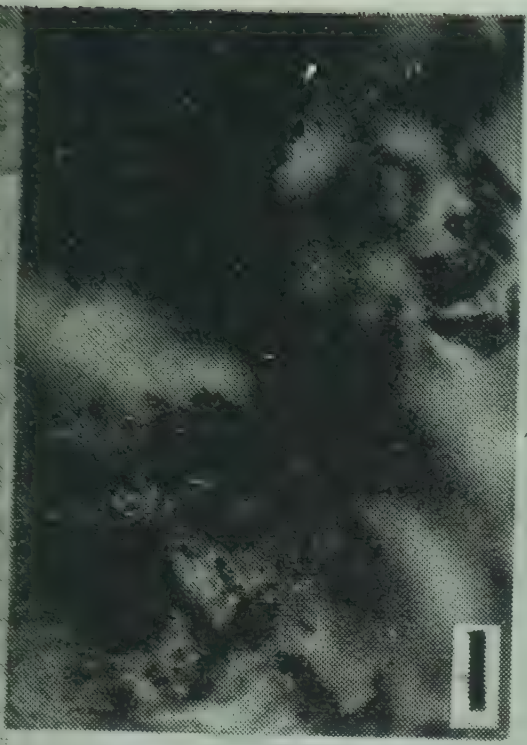
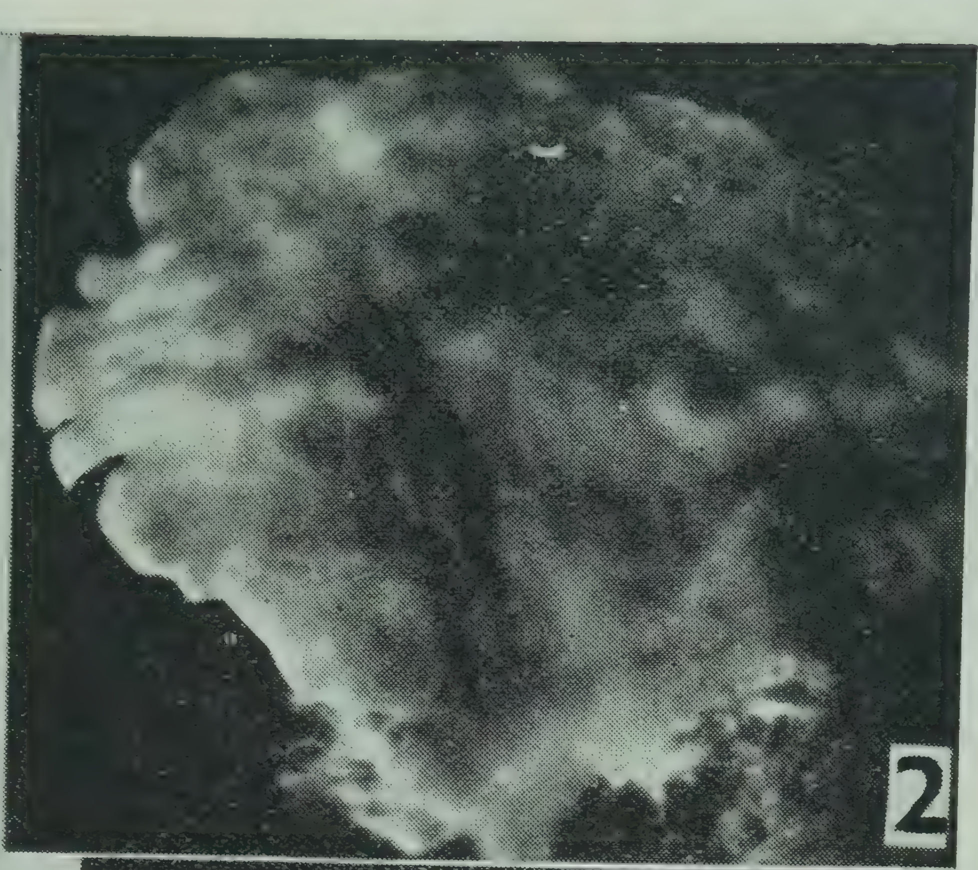
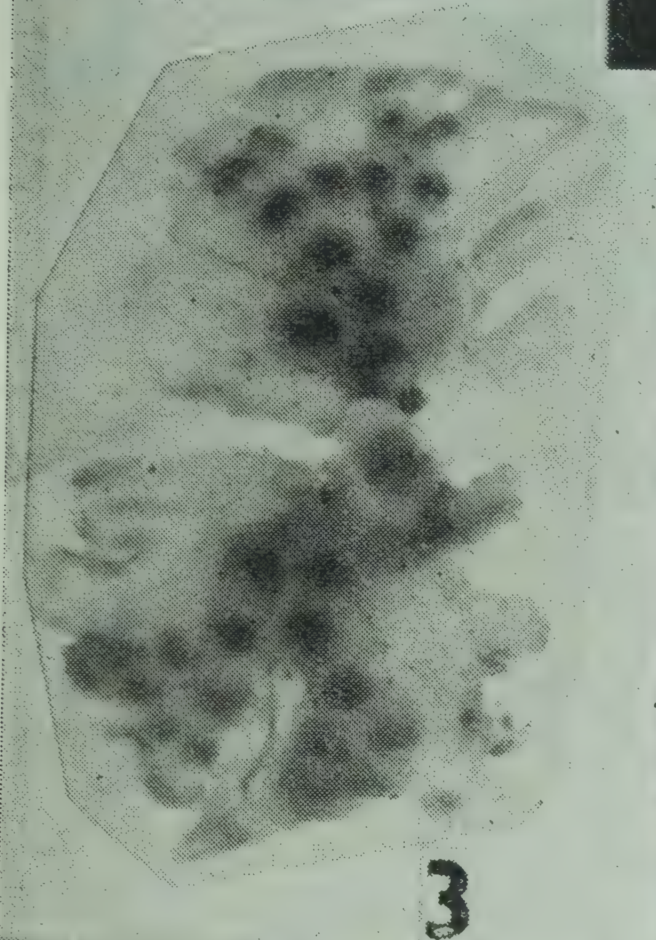
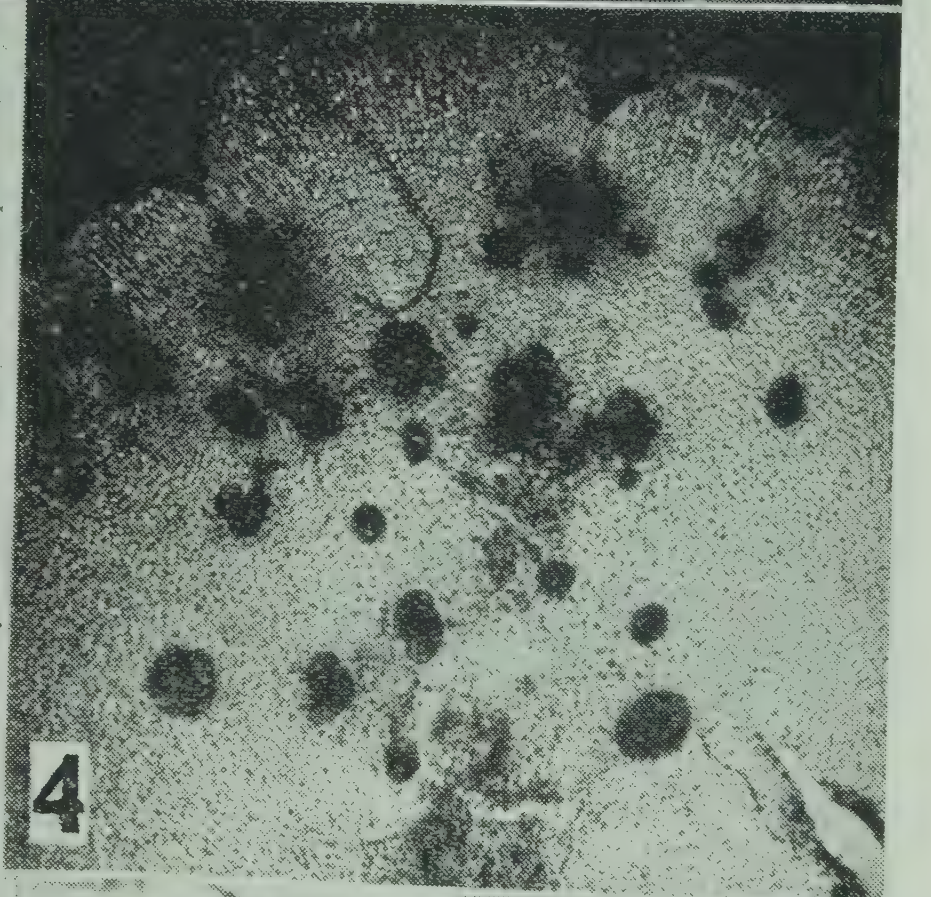
Fig. 8. Antheridial chamber of *Anthoceros mangaloreus*. × 17. Fig. 9. Same of *Phaeoceros communis*. × 17. Fig. 8A. Antheridium of *Anthoceros* (after Bharadwaj, 1958). × 19. Fig. 9A. Same of *Phaeoceros* (after Proskauer, 1951). × 17. Fig. 10. Young sporophyte of *Anthoceros* (after Bharadwaj, 1958). × 200. Note the foot cells. Fig. 11. Same of *Phaeoceros* (after Campbell, 1918). × 225. Note the foot cells. Fig. 12. T.s. thallus of *Anthoceros physocladus*. × 143. Fig. 13. T.s. thallus of *Phaeoceros communis*. × 143.

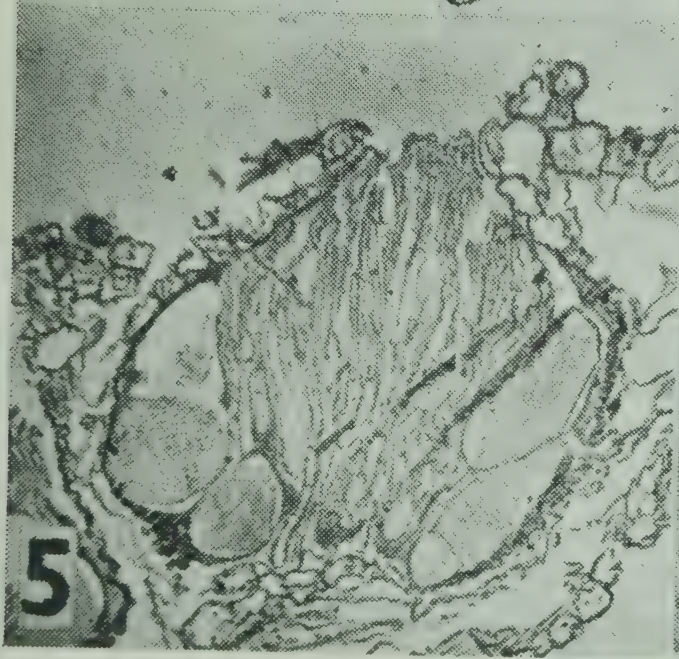
(Photograph plate I)











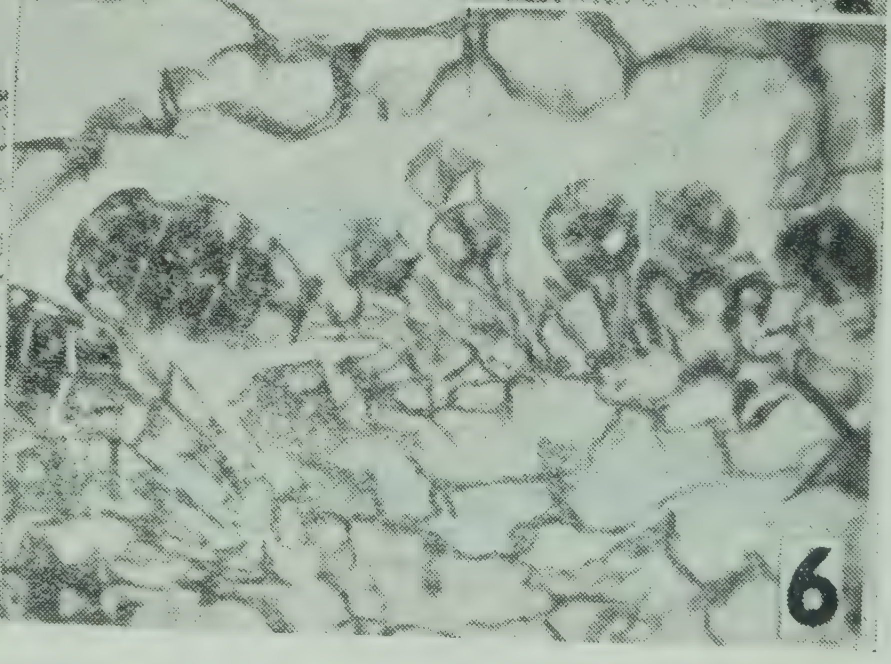
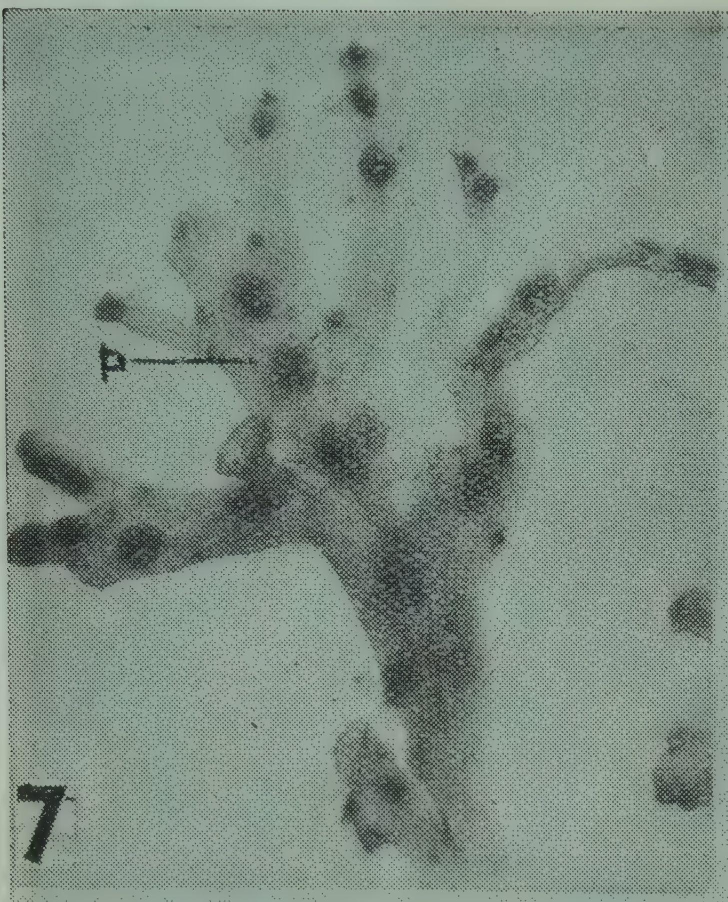
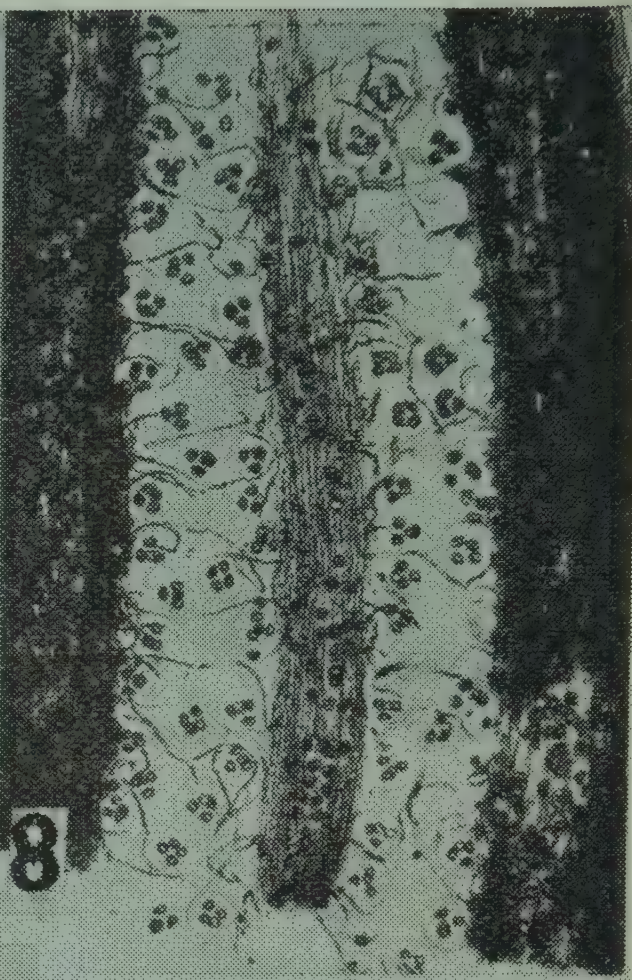
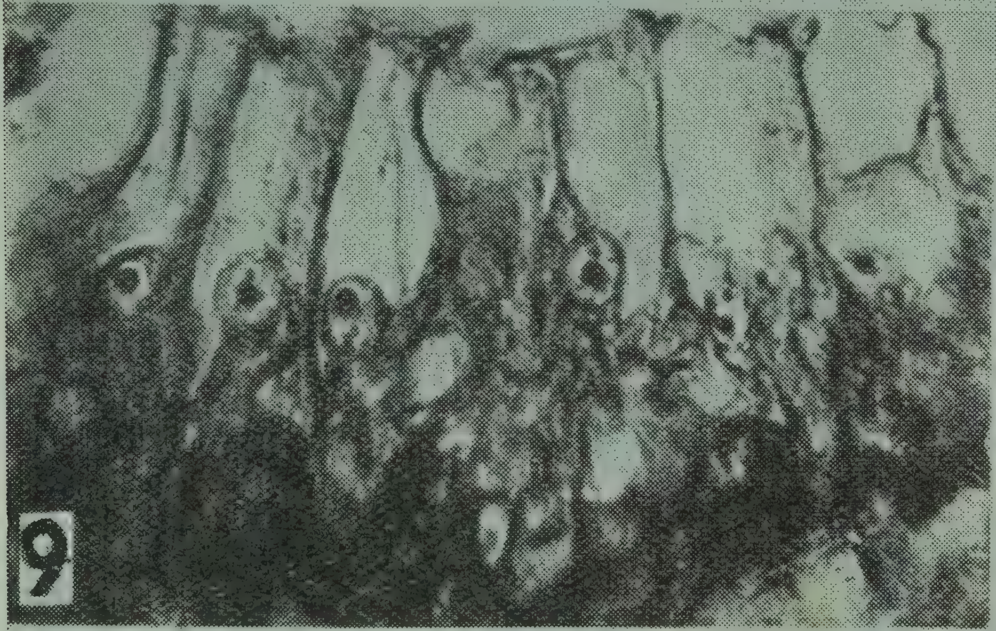


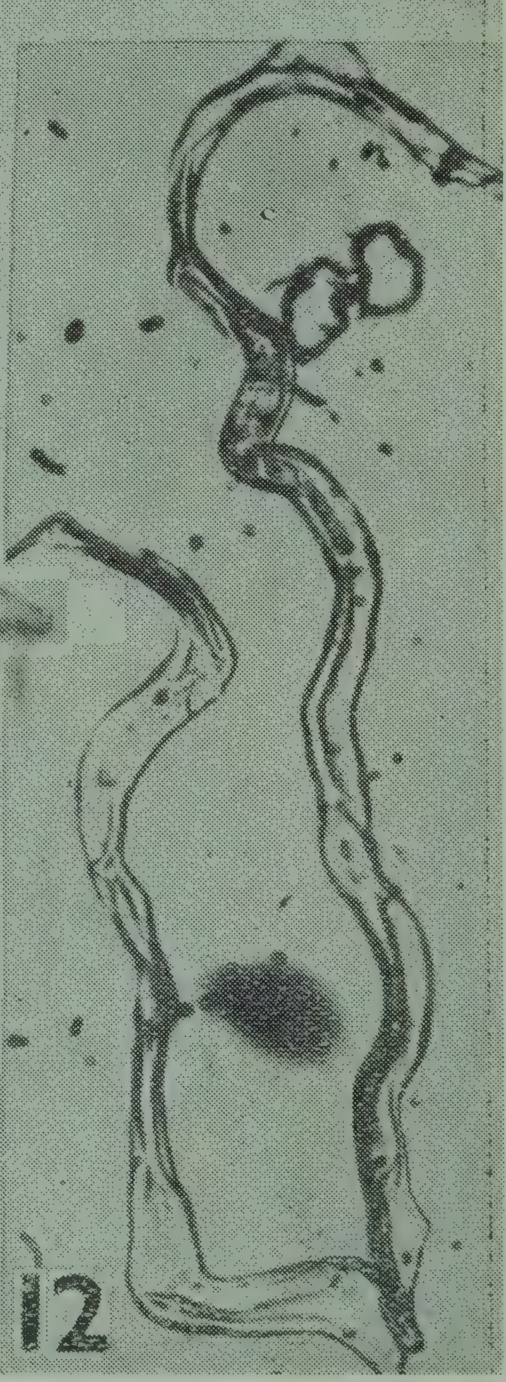
Fig. 1. Antheridial chamber of *Anthoceros punctatus*. × 42·5. Fig. 2. Male thallus of *A. mangaloreus*. × 12·4. Fig. 3. Same. × 6. Fig. 4. Thallus of *Phaeoceros communis* showing antheridial chambers and *Nostoc* colonies. × 22·5. Fig. 5. Vertical section through antheridial chamber of *A. mangaloreus*. × 100. Fig. 6. Antheridial chamber showing basal cushion of *A. mangaloreus* with antheridial buds. × 390.

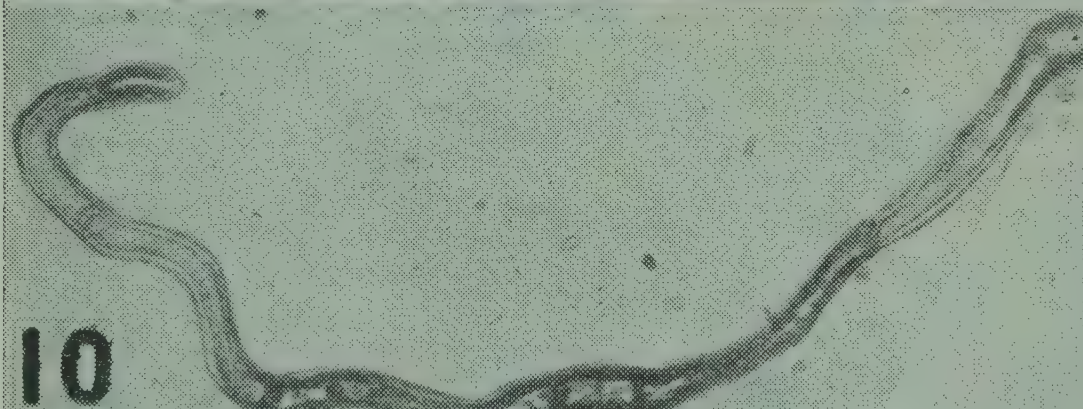
(Photograph plate II)











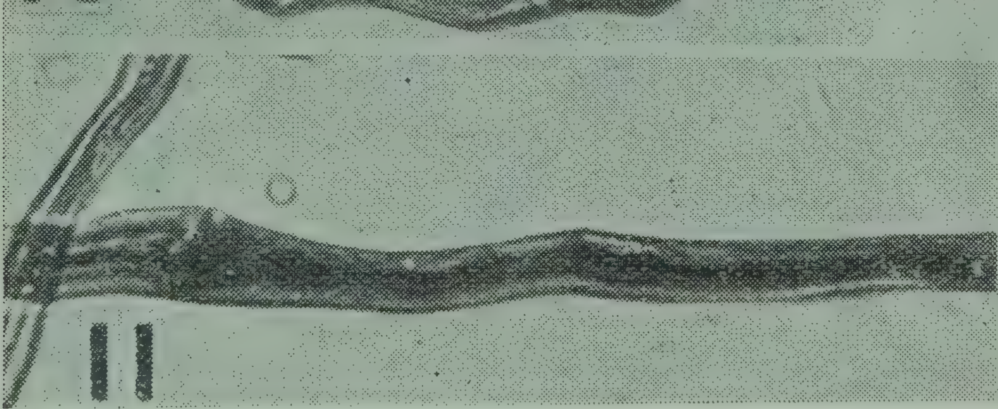


Fig. 7. Male thallus of *Anthoceros* cf. *gemmulosus*. × 5·2. *p., postule*. Fig. 8. Vertical section of the capsule of *A. mangaloreus*. × 60. Fig. 9. Lowermost layer of foot cells of *Anthoceros* cf. *gemmulosus*. × 650. Fig. 10. Elater of *A*. cf. *gemmulosus*. × 315. Fig. 11. Elater of *A. mangaloreus*. × 315. Fig. 12. Elater of *A*. cf. *maraguensis*. × 315.

SECTION OF ZOOLOGY AND ENTOMOLOGY

President :—Dr. Har Dayal Srivastava, M.Sc., D.Sc., F.Z.S.I., F.N.I.

PRESIDENTIAL ADDRESS

BLOOD-FLUKES

The subject of blood-flukes has been chosen for presidential address not merely because I have been working *inter alia* on the blood-flukes of Indian domesticated animals but also because they are interesting from the standpoint of pure zoological studies, and most of them are of very great medical and veterinary importance. My interest in this group of trematodes dates back to the early thirties when at the Allahabad University my Professor—Dr. H. R. Mehra, to whom I am grateful for initiating me into research in Helminthology, was working on the blood-flukes of chelonians.

The blood-flukes infecting warm blooded animals belong to the family Schistosomatidae Looss (1899) while those of fishes and chelonians to the families Sanguinicolidae Graff (1907) and Spirorchiidae Stunkard (1921) respectively ; the three families constituting the superfamily Schistosomatoidea Stiles and Hassall (1926). Members of the family Schistosomatidae infecting mammals have received the greatest attention owing to the importance of their hosts, and have evoked the interest of research workers all over the world.

Importance of Blood-flukes in Human and Animal Health

Blood-fluke infection, particularly in man and live-stock, retards the development of the young and breaks down the health and usefulness of the adult. The pathogenicity of schistosomes depends on several factors, such as the intensity and duration of infections and host-parasite relationships. The disease in man is caused principally by three species, *Schistosoma haematobium, S. mansoni* and *S. japonicum*. *S. haematobium* causes vesical schistosomiasis (also called urinary bilharziasis), which is a spectacular disease characterised by haematuria. These blood-flukes typically inhabit the veins of the urinary bladder and adjacent organs. The eggs deposited in the tissues, escape into the lumen of the organ, accompanied by blood and necrotic tissue cells. Some of the eggs are not able to reach the lumen of the bladder, but are attacked by leukocytes which produce an abcess around each egg, and the majority of these undergo fibrosis resulting in miliary pseudotubercle formation. The muscular coat of the bladder is hypertrophied and its capacity becomes diminished. Then phosphatic gravel or stones appear in lacunae in the bladder wall or free in its cavity. Gradually the ureter, renal pelvis, prostate, vesicula seminalis, vaginal wall, cervix and glans penis are also affected, being infiltrated by the ova. The organs show malignant growths and the passages are blocked. Apart from the involvement of the urinogenital organs, the eggs may be carried into the appendix resulting in schistosomal appendicitis and into the liver where pseudotubercle formation with consequent fibrosis and occasional gall stone formation occur. Eggs and even worms may invade the heart and the lungs. Rarely, the ova may reach the brain and spinal cord resulting in myelitis and mental disorders. In more rare cases the ova may reach the conjunctiva setting up visual disorders.

The original focus of vesical schistosomiasis was probably the Nile valley. Today, the disease is rampant in extensive areas of Egypt, Sudan, Ethiopia, Coastal Eastern Africa, vast areas in Central Africa including the Belgian Congo, Western Africa, isolated foci in Portugal, Corsica, Cyprus, Palestine, Arabia, Madagascar and Iraq. The incidence of the infection varies widely in the different areas reaching as high as 94 per cent in some. According to Stoll's (1947) estimation about 39·2 million people are infected, the great majority of which are in Africa.

In India, fortunately human schistosomiasis is not a serious problem. Upto the first half of this century, only about half a score of autochthonous cases of urinary schistosomiasis were reported. Gadgil and Shah (1952) reported the existence of an endemic focus of this infection in a village called Gimbvi in Ratnagiri District of Bombay State. Out of a population of about 1,200 approximately 250 persons were found to be infected.

Schistosoma mansoni produces a disease known as Manson's intestinal schistosomiasis. The adults live primarily in the small venules of the inferior mesenteric veins, secondarily in the radicles of the superior mesenteric vein and intrahepatically in the portal veins. The parasite causes grave changes in the viscera. The eggs carried to the liver cause pseudotubercle formation resulting in cirrhosis and consequent ascites. The mucosa of the intestinal canal shows characteristic "sandy patches" which are due to the effete calcified eggs. Haematin pigment is deposited in the Kupffer cells in the liver. Usually the spleen undergoes hypertrophy, a condition known as Egyptian splenomegaly. The colon shows thickening of the mucosa, papillomata, pericolic tumours and polypi which may extrude from the anus. The lungs are also frequently affected resulting in complications which may even terminate in congestive heart failure. Rarely, the ova may reach the brain and the spinal cord and cause myelitis, epilepsy and sensory and vasomotor disturbances.

This infection also probably originated in Africa from where it got introduced into West Indies and South America as a result of trade in slaves. In Africa, the disease occurs in Upper Sudan, Ethiopia, Eritrea, Zanzibar, Rhodesia, Tanganyika, Kenya, Madagascar, Natal, Transvaal and Congo. In the Western Hemisphere infection occurs in Brazil, Venezuela, Dutch Guiana and West Indies. According to Stoll's (1947) estimate about 29·2 million people are infected with this parasite, of which 23 million are in Africa and the rest in the Western Hemisphere.

Schistosoma japonicum causes Oriental schistosomiasis. The adult parasites live in the small venules of the superior mesenteric vein, secondarily in the radicles of the inferior mesenteric vein and intrahepatically in the portal veins. The disease is similar to Manson's schistosomiasis, the liver, spleen and intestine being mainly affected. The pathological changes are however more pronounced in this infection mainly because of the larger output of ova by the females. The involvement of the brain by ova is also more frequent. This infection is common in China and Japan and in some endemic foci in the Philippines and Celebes. Stoll's estimate of the incidence of the disease totals 46 million. A few cases of human infection with animal schistosomes, based on the recovery of typical ova from the excreta, have been reported. Cercaria of blood-flukes of lower mammals and birds produce schistosome dermatitis in man.

Schistosomiasis in animals is caused by a number of parasites belonging to several genera. The more important parasites are : *Schistosoma bovis* occurring in cattle, sheep, goat and equines ; *S. japonicum* in cattle, buffalo, sheep, goat, equines, dog, pig and cat ; *S. indicum* in equines, camel, sheep, goat, cattle and rarely buffalo ; *S. spindale* in cattle, buffalo, sheep and goat ; *S. incognitum* in pig, dog and sheep ; *S. nasale* in cattle and buffalo ; *Orientobilharzia turkestanicum* in cattle, buffalo, sheep, goat, equines and camel ; *O. dattai* in cattle, buffalo, sheep and goat ; *Bivitellobilharzia loxodontae* and *B. nairi* in elephant. Of these, *S. bovis* has been recorded from Europe, South-Western Asia and Africa ; *S. japonicum* from the Far East ; *O. turkestanicum* from Russian Turkestan, Mongolia, Iraq and France, and *B. loxodontae* from Africa. All the rest occur in India. *O. turkestanicum* also has recently been known to occur in India (Srivastava and Trisal, 1957). In India, schistosomiasis in animals is therefore a problem of considerable magnitude and importance. Except *S. nasale,* all these species cause viscero-intestinal schistosomiasis which is more or less similar to the condition met with in man. *S. nasale* inhabit the veins of the nasal mucosa and cause marked rhinitis. The mucosa becomes full of small abscesses formed around ova of the parasite. Later, the proliferating epithelium gives rise to cauliflower-like growths leading to varying degree of obstruction of the nasal passage resulting in dyspnoea and snoring, which can be heard from a distance. There is profuse muco-purulent and sanguineous discharge from the nose. In extreme cases, the animal breathes through the mouth.

FAMILY SCHISTOSOMATIDAE

The family Schistosomatidae consists of four subfamilies : Schistosomatinae Stiles and Hassall (1898), Bilharziellinae Price (1929), Dendritobilharziinae Mehra (1940) and Gigantobilharziinae Mehra (1940). Members of the subfamily Schistosomatinae occur in birds and mammals, and those of the other three subfamilies exclusively in birds. Schistosomatinae comprises the genera *Schistosoma* Weinland (1858), *Ornithobilharzia* Odhner (1912), *Austrobilharzia* Johnston (1917), *Macrobilharzia* Travassos (1923), *Schistosomatium* Tanabe (1923), *Heterobilharzia* Price (1929), *Microbilharzia* Price (1929), *Bivitellobilharzia* Vogel and Minning (1940), *Orientobilharzia* Dutt and Srivastava (1955) and *Sinobilharzia* Dutt and Srivastava (1955). Of these, *Schistosoma, Schistomatium, Heterobilharzia, Bivitellobilharzia* and *Orientobilharzia* infect mammals and the rest birds.

Though the first blood-fluke to be discovered was an avian parasite — *Ornithobilharzia canaliculata* (Rudolphi, 1819) Odhner (1912), man was harbouring blood-flukes in his veins from times immemorial. The presence of schistosome ova in mummies which fell 3,000 to 4,000 years ago has been reported by Sir Armund Ruffer (1910), who also demonstrated microscopically the presence of calcified blood-fluke ova in the nuclei of urinary calculi and in the cortex of kidneys of mummies (1200-1090 B.C.). Ancient Egyptian physicians were acquainted with haematuria and had several prescriptions for its treatment. They of course did not know its parasitic nature and thought that it was effected through the urethra. The prophylactic measures recommended were the use of penis shield, ancient equivalent of French letter (Leiper) and circumcision (Madden). Bilharz (1852) was the first to discover a human blood-fluke in the portal vein of an Egyptian peasant at Kasr-El-Aini and designated it as *Distoma haematobium.* Cobbold in 1859 suggested a new genus — *Bilharzia* — for the parasite, in honour of its discoverer, but three months earlier Weinland (1858) had named it *Schistosoma* and thus the parasite became *S. haematobium* (Bilharz, 1852) Weinland (1858). Sonsino (1876) described *Bilharzia bovis* a blood-fluke from a bull in Egypt, which Blanchard (1895) transferred to the genus *Schistosoma.*

While studying the bladder disease, Bilharz (1852) noticed the presence of lateral spined ova in the uteri of female schistosomes. He believed that he had seen the lateral spined and terminal spined ova in the same female. In this he was obviously mistaken. He thought that they might equally affect the digestive tract and the ova in the faeces might be terminal or lateral spined. He regarded the terminal spined eggs as normal and lateral spined as deformed. Looss tenaciously maintained that the two types of ova belonged to the same species and that the unfertilised females produced the deformed eggs, i.e. lateral spined. The presence of miracidium in such eggs was attributed to parthenogenesis. Sonsino first suggested that there were two species of parasites producing the two types of ova but later on put forth the postulate that one form of ova produced the males and the other females of the same species. Castellani (1902) in Uganda and Manson (1903) in London reported the presence of lateral spined ova in faeces of patients whose urine was negative for schistosome eggs. Manson's patient had lived in the islands of West Indies but never in Africa and had never suffered from haematuria. Manson therefore thought that possibly there were two species of blood-flukes, one with lateral spined ova depositing its eggs in the rectum only and the other haunting the rectum or bladder indifferently. On the basis of the distinctive characters of the lateral spined ova, their association with dysentery, geographical distribution and anatomical habitat Sambon (1907) created a new species and named it *S. mansoni* after Manson who had first suggested the separation of the two species. However, a vituperative controversy raged over the validity of Sambon's species till Holcomb (1907) in West Indies and Piraja da Silva (1909) in Brazil described the anatomy of the adult worms.

The symptoms caused in man by the oriental human scistosome were known in Japan for a long time. Mazimi (1888) reported for the first time that there existed in Japan a hepatic cirrhosis produced by the ova of an unknown trematode. Katsurada (1904) found characteristic ova in the stools of five out of twelve patients. He suspected the disease to be caused by the eggs and their adult worms to be present in the portal system. As he did not find adult parasites in man he examined dogs and cats from endemic areas. From the portal system of the latter he obtained several specimens of a blood-fluke, which he described as a new species—*S. japonicum.* Simultaneously and independently, Fujinami found the charactertistic ova in the various organs and a parasitic worm in the portal vein of a man. He however wrongly considered it as *S. haematobium.*

Montgomery (1906) described three new species from Indian domestic animals, viz. *S. indicum* from equines and *S. spindale* and *S. bomfordi* both from cattle. The last species was transferred by Price (1929) to *Ornithobilharzia* but Dutt and Srivastava (1955) have assigned it to *Orientobilharzia.* On the basis of the shape of a new type of schistosome ova with subterminal spine obtained from presumably human faeces in Bengal, Chandler (1926) created a new species *Schistosoma incognitum.* Adult schistosomes with typical ova described by Chandler were recovered from pigs by Rao and Ayyar (1933) and described as *Schistosoma suis*, n. sp. Bhalerao (1938) suggested that the two species were synonymous, which has been established by Sinha and Srivastava (1956) in their studies on the morphology and life history of *S. incognitum*. Rao and Ayyar (1935) and Srivastava (1942) reported the occurrence of this species in Indian dogs. From South African sheep Veglia and Le Roux (1929) described *Schistosoma matheei* which has been regarded as a synonym of *S. bovis* by some workers (MacHattie and Chadwick, 1932 ; Bhalerao, 1932), and as a variety of it by Van den Berghe (1937). But its validity has been upheld by Alves (1949) who showed by biometric studies that its ova could be distinguished from those of *S. bovis* and *S. haematobium*. Brumpt (1931) reportd two species from Africa—*Schistosoma curassoni* sp. inquir. from cattle and *S. rodhaini* from rodents. The former being closely related to *S. mattheei* is of doubtful validity (Bhalerao, 1932 ; Kuntz, 1955). *Schistosoma margrebowiei* was described by Le Roux (1933) from cattle, zebra and antelopes in Africa.

Except Himachal Pradesh, Punjab, Rajasthan, Madhya Pradesh and the major part of Uttar Pradesh, nasal granuloma in cattle occurs over wide areas in India. The disease has also been met with rarely in goats and once in a pony. The causative parasite of the disease was discovered by Rao (1933) who described it as *Schistosoma nasalis*, n. sp., though its schistosomal etiology had been suspected by previous workers. A morphologically identical blood-fluke occurs in the nasal veins of buffaloes in several parts of the country, even in regions where nasal granuloma in cattle does not occur. The infection is almost asymptomatic, though in the nasal discharge of the infected buffalo characteristic eggs of *S. nasale* are present.

Fisher (1934) reported a new species of human schistosome, *Schistosoma intercalatum* from Belgian Congo, differentiating it from *S. haematobium* and *S. bovis* on the basis of the size of ova. Van den Berghe (1937) regarded it as a variety of *S. haematobium* but Schwetz (1951) and others have accepted it as a valid species. From an Indian elephant Mudaliar and Ramanujachari (1945) described a new blood-fluke—*Schistosoma nairi*, which was transferred to *Ornithobilharzia* by Bhalerao (1947) but has been correctly assigned by Dutt and Srivastava (1955) to *Bivitellobilharzia*. The blood-fluke is known to infect Indian elephants in various parts of the country. *Schistosoma leiperi* was described by Le Roux (1955) from *Tragelaphus spekei selousi* and other herbivora in Northern Rhodesia.

Le Roux (1958) has proposed three new genera, viz. *Afrobilharzia* for *Schistosoma mansoni* and *S. rodhaini* ; *Sinobilharzia* for *S. japonicum*, and *Rhodobilharzia* for *S. margrebowiei*. The separation of these species from the genus *Schistosoma* is unwarranted in view of the close similarity in the morphology of the adults and cercariae of *S. mansoni* and *S. japonicum* to that of the other species of the genus. The main difference between *S. japonicum* and *S. margrebowiei* is the presence of tuberculate cuticle in the latter and smooth cuticle in the former, which is only a specific difference.

The second genus of mammalian blood-fluke was created by Tanabe (1923) and designated as *Schistosomatium*. The parasite—*S. pathlocopticum*—was raised experimentally in white rats and mice from a cercaria obtained from *Lymnaea palustris*. After an examination of Tanabe's original material Penner (1942) reported that the species described by

Tanabe was synonymous with *Schistosomatium douthitti* (Cort, 1914) Price (1931). The musk shrew and meadow mouse were reported by Price to be the definitive natural hosts of the parasite.

The genus *Heterobilharzia* was created by Price (1929) for male schistosomes parasitic in *Lynx* sp. in North America. Vogel and Minning (1940) described a schistosome from African elephants and named it *Bivitellobilharzia loxodontae*, gen. et sp., nov. The second species of the genus, *B. nairi* (Mudaliar and Ramanujachari, 1945) Dutt and Srivastava (1955) was described from an Indian elephant.

Another genus—*Orientobilharzia*—of mammalian schistosome was created by Dutt and Srivastava (1955). The authors had discovered a new mammalian schistosome infecting Indian sheep, goat, cattle and buffaloes, and in a preliminary report (1952) assigned it tentatively to *Ornithobilharzia*, as *O. dattai*, n.sp., mainly following Price's (1929) reallocation to this genus of two allied mammalian blood-flukes—*Schistosoma bomfordi* Montgomery (1906) and *S. turkestanicum* Skrjabin (1913). Subsequent detailed studies convinced the authors that the above three mammalian schistosomes were not congeneric with the avian species of *Ornithobilharzia*. They (1955) therefore created a new genus *Orientobilharzia* with *Orientobilharzia dattai* (Dutt and Srivastava, 1952) n. comb., as the type species, and they transferred *Ornithobilharzia bomfordi* and *O. turkestanicum* to the new genus. *O. bomfordi* has not been met with again ever since first described by Montgomery in 1906. Its occurrence in cattle in France reported by Marotel (1908) was shown to be erroneous by Price (1929) who regarded it as *O. turkestanicum*. Le Roux (1958) appears to consider *O. turkestanicum* as synonymous with *O. bomfordi* when he says, "The inclusion of *Schistosomum bomfordi* Montgomery, 1906, from *Bos indicus* in India, and *Bos taurus in France and Russian Turkestan, and various domesticated animals in Iraq and Catra* [*sic*] *hircus in China* in the genus *Ornithobilharzia* Odhner, 1912, was evidently based exclusively on the number of testes and not on morphological characters. This mammalian bloodfluke is therefore removed from its grouping with avian bloodflukes to a new genus *Eurobilharzia* with *Eurobilharzia bomfordi* (Montgomery, 1906) as the type. In this genus the dorsal surface of the male is studied with tubercles armed with spines ; testes numerous numbering upto 60 or more ; ovary situated close to the ventral sucker ; uterus very short and with never more than one egg in it ; egg oval with a well-developed subterminal spine and *with a knob-like projection at its anterior pole*". (Italics mine).

From the above statement it is clear that Le Roux has ignored the taxonomic significance of the characteristic differences in the shape of the eggs and the nature of the cuticle in *O. bomfordi* and *O. turkestanicum*. Evidently he was unaware of the creation of the genus *Orientobilharzia* for *O. bomfordi, O. turkestanicum* and *O. dattai* which are undoubtedly three distinct species. MacHattie (1936) has already pointed out that the tubercles described by Bhalerao (1932) in certain specimens of *O. turkestanicum* were actually contractions of the cuticle and not tubercles at all. Our studies of Bhalerao's material and of specimens collected by us have confirmed this.

The first avian genus of Schistosomatinae—*Ornithobilharzia*—was created by Odhner (1912) for *O. intermedia,* n.sp. He also transferred to the new genus *Distoma canaliculata* Rudolphi (1819) and *Bilharziella kowalewskii* Parona and Ariola (1896). Faust (1924) described *O. odhneri,* n.sp., from China, for which Dutt and Srivastava (1955) proposed a new genus *Sino-*

bilharzia. A number of species of *Ornithobilharzia* have been described from birds in different countries.

The genus *Austrobilharzia* was created by Johnston (1917) for a new schistosome *A. terrigalensis.* Travassos (1923) proposed the genus *Macrobilharzia* with *M. macrobilharzia* as genotype. Price (1929) suppressed this genus as a synonym of *Ornithobilharzia* but in 1931 he reported that the female specimens of schistosomes which he had described in 1929 as *Paraschistosomatium anhingae* were the females of *Macrobilharzia.* He thus revived *Macrobilharzia* and dropped *Paraschistosomatium* as its synonym. On the basis of close morphological resemblance between *M. macrobilharzia* and *Ornithobilharzia baeri* described by him, Fain (1955) has placed *Macrobilharzia* and *Paraschistosomatium* as synonyms of *Ornithobilharzia.* In 1929 Price created the genus *Microbilharzia* for *Ornithobilharzia* sp. Chapin (1924) and named it *M. chapini.* Stunkard and Hinchliffe (1951) raised the adults of *Cercaria variglandis* (Miller and Northup, 1926) experimentally in birds and described them as *M. variglandis.* They (1952) showed that this species was morphologically identical with *M. chapini.* Penner (1953) from a study of a large number of worms raised experimentally in birds from *Cercaria variglandis* and of the type material of *M. chapini* concluded that *Microbilharzia* was a synonym of *Austrobilharzia* as emended.

Dutt and Srivastava (1955) proposed a new genus *Sinobilharzia* for *Ornithobilharzia odhneri* Faust (1924) because of its morphological peculiarities. In those genera of Schistosomatinae in which the ovary is just cephalad of the caecal union, the vitellaria is single and co-extensive with the common caecum, viz. *Schistosoma, Orientobilharzia, Ornithobilharzia* (except *O. odhneri*), *Microbilharzia* and *Austrobilharzia.* In others, where the ovary is situated far ahead of the caecal union and where the intestinal caeca are long and the common caecum very short, the vitellaria is double, each set running along each intestinal caecum, viz. *Bivitellobilharzia* and *Schistosomatium.* But in *O. odhneri* the ovary is situated in the anterior third and the intestinal caeca unite near the posterior quarter of the body but there is a single set of vitellaria. In this species the position of the anterior most testis is much further back than in the species of *Ornithobilharzia.*

The subfamily Bilharziellinae Price (1929) consists of the genera *Bilharziella* Looss (1899) with *B. polonica* (Kowalewski, 1895) as type species and *Trichobilharzia* Skrjabin and Zakharow (1920). The genus *Chinhuta* Lal (1937) was suppressed by Mehra (1940) and its type species *C. indica* has been suppressed by McMullen and Beaver (1945) as synonym of *Bilharziella polonica* (Kowalewski, 1895) Looss (1899). Skrjabin and Zakharow (1920) described *Trichobilharzia kossarewi,* gen. et sp., nov., from ducks in Russia. Brumpt (1931) reported that *cercaria ocellata* La Valette (1854) developed into adults identical with *T. kossarewi,* and thus *T. ocellata* became the type species. McMullen and Beaver (1945) suppressed *Pseudobilharziella* Ejsmont (1929) as a synonym of *Trichobilharzia* and transferred its species to the latter genus. Of the large number of species described under this genus, three, viz. *T. rodhaini, T. nasicola* and *T. spinulata* Fain (1955) occur in the veins of the nasal mucosa and submucosa of aquatic birds in Belgian Congo.

The subfamily Dendritobilharziinae Mehra (1940) contains only one genus *Dendritobilharzia* Skrjabin and Zakharow (1920) with *D. pulverulenta* (Braun, 1901) Skrjabin (1924) as its type species. The only Indian species of the genus is *D. asiatica* Mehra (1940). Gigantobilharziinae

Mehra (1940) also contains a single genus, *Gigantobilharzia* Odhner (1910) with *G. acotylea* as its genotype. Only one species—*G. egreta* Lal (1937 —has been reported from India.

FAMILY SPIRORCHIIDAE.

The first blood-fluke from turtle was reported by Leared (1862) under the name *Distoma constrictum*. As this name was preoccupied Monticelli (1896) named it as *Mesogonimus constrictum* (Leared), but Looss (1899) erected the genus *Hapalotrema* for this species. MacCallum (1918) created *Spirorchis*, gen. nov., for a new species of blood-fluke from *Chelopus insculptus* but he did not give it a specific name. Stunkard (1921) erected the new family Spirorchiidae to include the genera *Spirorchis* and *Hapalotrema* and placed them under separate subfamilies: Spirorchiinae and Hapalotrematinae. Ward (1921) named MacCallum's undesignated species of *Spirorchis* as *S. innominata* which thus became the type species of the genus. Three new species and genera were described from North America: *Hapalorhynchus gracilis* Stunkard (1922), *Unicaecum ruszkowskii* Stunkard (1925) and *Vasotrema amydae* Stunkard (1926). Ejsmont (1927) added two more genera *Diarmostorchis* and *Spirhapalum* with *D. blandingi* (MacCallum, 1926) n. comb. and *S. polesianum* as the type species respectively.

Mehra (1933) described a new genus *Coeuritrema* with *C. lyssimus* as type species. The same year Thapar described *Tremarhynchus indicus*, gen. et sp., nov., but Mehra (1934) pointed out the synonymy of the two genera and retained *Coeuritrema* on the basis of priority of publication. In the same paper Mehra described *Plasmiorchis* with *P. orientalis* as the type species and erected a new subfamily Unicaecuminae for *Unicaecum*. Price (1934) added three new genera—*Amphiorchis, Learedius* and *Neospirorchis* with *A. amphiorchis, L. leardi* and *N. schistosomatoides* respectively as the type species. Mehra (1939) described two more new genera—*Hemiorchis* and *Monticellus*—with *H. hardellii* (Mehra, 1934) and *M. indicus* Mehra (1939) as type species respectively. A year later Mehra added *Enterohaematotrema palaeorticum*, gen. et sp., nov. Byrd (1939) pointed out that the genera *Spirhapalum* Ejsmont (1927) and *Plasmiorchis* Mehra (1934) were synonymous with the genera *Hapalotrema* Looss (1899) and *Spirorchis* MacCallum (1918) respectively, but Skrjabin (1951) and Yamaguti (1958) have retained them. Manter and Larson (1950) described *Carettacola*, n.g., *with C. bipora* as the type species. Skrjabin (1951) erected the subfamily Neospirorchiinae for *Neospirorchis* Price (1934). Martin and Bamberger (1952) described *Haemoxenicon*, n. gen., with *H. stunkardi* as its type species.

Yamaguti (1958) has created five new subfamilies: Amphiorchiinae for *Amphiorchis*; Carettacolinae for *Carettacola* and *Haemoxenicon*; Hapalorhynchinae for *Hapalorhynchus*; Vasotrematinae for *Vasotrema* and Tremarhynchinae for *Tremarhynchus* and *Enterohaematotrema*. Under Tremarhynchinae he has included *Coeuritrema* as a synonym of *Tremarhynchus*, but this is obviously untenable on account of the priority of the former genus and therefore the subfamily should be named Coeuritrematinae. Thus, the family at present consists of about seventeen genera included in nine subfamilies. The species described so far number more than fifty. The validity of all the genera and species needs to be examined.

FAMILY SANGUINICOLIDAE

Odhner (1900) described the first blood-fluke from fishes as *Aporocotyle simplex.* He had obtained the parasite from the gill of *Pleuronectes* sp. and considered it to be an ectoparasite. Plehn (1905) described *Sanguinicola armata* and *S. inermis* from the circulatory system of fishes. These were regarded as parasitic turbellarians belonging to a new family of Rhynchostosmida, and Graff (1907) proposed the family Sanguinicolidae for them. Plehn (1908) considered these parasites as monozoic cestodes. Linton (1910) described another parasite apparently from the intestine of *Kyphosus* sp. and assigned it to a new genus as *Deontacylix ovalis.* Odhner (1911) reported that the species of *Sanguinicola* described by Plehn were digenetic trematodes and *A. simplex* was a blood-fluke. Odhner (1912) proposed a new family Aporocotylidae to include these blood-flukes of fishes. Stunkard (1923) assigned *Deontacylix ovalis* to the family Aporocotylidae. Rasin (1929) described *Janickia volgensis* from fishes but Skrjabin (1951) dropped the genus as synonym of *Sanguinicola.* Goto and Ozaki (1929) described *Plehnia japonicum* but later they (1930) proposed a new generic name, *Psettarium* as *Plehnia* was pre-occupied. McIntosh (1934) added another new genus, *Paradeontacylix* with *P. sanguinicoloides* as the type species. Szidat (1951) described *Plehniella coelomicola,* gen. et sp., nov. Two more new genera were added by Short (1953, 1954) : *Cardicola* with genotype *C. cardicola* (Manter, 1947) and *Selachohemecus* with genotype *S. olsoni.*

There appears to be much anomaly in the nomenclature of the family of blood-flukes of fishes. Although Sanguinicolidae Graff (1907) has priority over Aporocotylidae Odhner (1912) which becomes a synonym (cf. Skrjabin, 1951), most of the authors have been designating the family as Aporocotylidae, and some have recognised both families as valid. Yamaguti (1958) retains Aporocotylidae for *Aporocotyle* and puts the rest of the genera under Sanguinicolidae. This appears to be untenable in view of the close similarity of *Aporocotyle* with the other genera of Sanguinicolidae. *Aporocotyle* may at best be included in a new subfamily Aporocotylinae under Sanguinicolidae, which has been divided by Yamaguti into four subfamilies : Sanguinicolinae (genera *Sanguinicola* and *Paradeontacylix*) ; Cardicolinae (genera *Cardicola* and *Selachohemecus*) ; Deontacylicinae (genus *Deontacylix*) and Psettarinae (genus *Psettarium*).

LIFE-HISTORIES

The history of the early efforts to elucidate the life-cycle of *Schistosoma haematobium,* following the discovery of its adults by Bilharz (1852), is interesting and provides instances of investigators being deflected from the path of success as a result of preconceived ideas. Commenting on Griesinger's (1854) suggestion that schistosomula existed in the waters of the Nile, in fishes, or even in bread, grain and fruit, Cobbold as early as 1864 remarked that it was more probable that the larvae in the form of cercariae, rediae and sporocysts would be found in certain gastropod molluscs. Direct infection in rabbit and dog was attempted by Harley (1871) by feeding them mucus containing numerous eggs. Relying on Chatin's view that the presence of germinal cells in the miracidium of the blood-fluke indicated preparation for a metamorphosis as in other trematodes, Sonsino (1883) examined a large number of Egyptian snails for the presence of cercariae with negative results. In 1888 Allan put forth the hypothesis that the unknown larva probably entered the body through the skin as he had obeserved that while boys bathing in certain waters became infected, the girls who did not bathe remained free from infection. An outstanding heleminthologist of the time with extensive research work to his credit, Arthur Looss tried unsuccessfully to elucidate the life-history. Having failed to find the molluscan host, he (1894) propounded his famous hypothesis that the miracidium was the infective stage and that man acted both as intermediate and final host. According to this the miracidium entered the body through the skin, developed into sporocyst in the liver and the worms escaped into the portal system. Despite the increasing volume of scientific data against his hypothesis, Looss surprisingly stuck to it and because of his world-wide reputation as a research worker and his able dogmatic advocacy of his hypothesis affected adversely the work of other investigators for many years.

To Miyairi and Suzuki (1913) goes the honour of the first discovery of the life-history of a schistosome. Working with *S. japonicum* they discovered that a mollusc served as the intermediate host and that the infective form was a cercaria as actually suggested by Cobbold fifty years ago. They (1914) were also able to infect snails with miracidia and traced their transformation into the first generation sporocyst which produced a second generation of larvae, incorrectely described as rediae, which gave rise to cercariae. They successfully infected a mouse by immersing its body in water containing the carcariae and recovering numerous schistosomes from its liver after three weeks. Miyagawa (1913) working independently proved that *S. japonicum* had a molluscan intermediate host—the Katayama snail (=*Onchomelania nosophora*)—and that the infective larva was a fork-tailed cercaria. This was the turning point in the studies on the life-histories of schistosomes, and a number of helminthologists in several countries have since made valuable contributions to the knowledge of the different aspects of the biology of the blood-flukes. Leiper and Atkinson (1915), who were working on schistosome problem in Egypt, visited China and Japan and successfully repeated the experiment of Miyairi and Suzuki and of Miyagawa. On return to Egypt Leiper (1915) discovered that *S. haematobium* and *S. mansoni* had similar life-cycles. He proved that *Bulinus* sp. served as the intermediate host of *S. haematobium* and *Planorbis boissyi* for *S. mansoni*. Subsequent researches have shown that several species of the genera *Bulinus, Physopsis, Physa, Lymnaea* and *Planorbis* might act as the intermediate hosts of *S. haematobium*. But most startling has been the report of Rao, Gadgil and Shah (1953) that *Paludomus obesa,* an operculate snail of the family Melanidae, might possibly serve as the intermediate host of *S. haematobium* in India. Gadgil and Shah a year later reported *Ferrissia tenuis,* a tiny snail of yet another family Ancylidae, as its experimental and "most probable" intermediate host. *S. mansoni* has a more restricted intermediate host specificity and only Planorbid snails of the genera *Planorbis, Biomphalaria, Australorbis* and *Tropicorbis* serve as its intermediate hosts.

Liston and Soparkar (1918) elucidated the life-history of *Schistosoma spindale* and found *Indoplanorbis exustus* as its intermediate host. They experimentally infected guinea-pigs and kids and studied the development of the parasite in the molluscan host. Soparkar also mentioned *Lymnaea acuminata* as another intermediate host and this was confirmed by Peter (1955). *L. luteola* was incriminated by Bhalerao (1943) but Dutt and Srivastava did not find the cercaria of this blood-fluke in any snail other than *I. exustus*. Fairley and Mackie (1930) and Rao (1934) confirmed the observations of Liston and Soparkar and reported that only male worms developed in the guinea-pig. However, Dutt (1957) found that the female of *S. spindale* also developed in the guinea-pig. He also experimentally infected a horse with *S. spindale* cercariae, but no viable ova were produced in the equine host. Cawston (1920) raised *S. bovis* from cercariae obtained from *Physopsis africana* while Brumpt (1930) reported *Bulinus contortus* as another intermediate host and infected mice, rats, guinea-pigs and rabbits. The life history of *Schistosomatium douthitti* (=*S. pathlocopticum*) was worked out by Tanabe (1923) who had raised the blood-fluke experimentally in white rats and mice from a cercaria obtained from *L. palustris.* Price (1931) added *L. stagnalis* and *Physa gyrinae* also as its intermediate hosts. *P. africana* was found by Veglia and Le Roux (1929) to act as the intermediate host of *S. mattheei.* The life-history of *S. nasale* was worked out by Rao (1933) who found that *Cercariae indicae* XXX Sewell (1922) obtained from *I. exustus* and *Lymnaea luteola* developed into the blood-fluke and several calves were successfully infected by him. Srivastava and Dutt found that only very young specimens of the snail *I. exustus* could be infected with the miracidium of this species. Several calves, a goat and a few white mice were successfully infected. In the white mice the worms did not mature and were found in the lungs. Khaw (1947) reported that *I. exustus* served as the intermediate host of *S. indicum* having infected rabbits with cercariae from it but did not describe the cercaria or give any details of the experiment. Srivastava and Dutt (1951, 1955) studied in detail the life-history and biology of the parasite. *I. exustus* was found to act as the experimental and natural intermediate host. Goat, sheep, donkey, buffalo-calf, rabbit, guinea-pig, white rat, white mouse were experimentally infected. Khaw (l.c.) obtained adults of *S. incognitum* (Syn. *S. suis*) after infecting rabbits with cercariae from naturally infected *L. luteola* f. *succinea* or *ovalis.* Sinha and Srivastava (1954, 1956) investigated the life history and biology of *S. incognitum* in detail, and found *L. luteola* f. *australis* as the intermediate host. In addition to pigs and dogs, a number of laboratory mammals and domestic ruminants were found to be susceptible hosts. Schwetz (1951) found that *Planorbis pfeifferi* served as the intermediate host and rodents as definitive hosts of *S. rodhaini.* Fisher (l.c.) reported *P. africana* to be the intermediate host of *S. intercalatum* and successfully infected mice and sheep with the cercariae from the snail. The intermediate host of *S. leiperi* was found to be *Bulinus* (*Physopsis*) *africana* by Le Roux (1955) who experimentally raised the parasite in white mice. The life-history of *S. margrebowiei* is not known so far.

The life-history of *Orientobilharzia turkestanicum* was worked out by MacHattie (1936) in Iraq, who found *Lymnaea tenera euphratica* to be the intermediate host. White mice and rabbits were successfully infected with the cercaria. Abdussalam and Sarwar (1954) reported *L. acuminata* f. *rufescens* as the intermediate host of *O. turkestanicum* in Pakistan. Guinea-pig and lamb were experimentally infected by them. Dutt and Srivastava (1952, 1955) described the life-history and biology of *O. dattai. L. luteola* f. *australis* was found to be the intermediate host and buffaloes, cattle, sheep and goats were reported to be the natural definitive hosts, and these and donkey, rabbit, guinea-pig, rat and white mouse were susceptible to experimental infection. Of the many species of *Ornithobilharzia,* the life-history of only *O. canaliculata* (Rudolphi 1819), Odhner, 1912 is known so far. Penner (1953) obtained the adult parasites from young pigeons exposed to cercaria from *Batteilaria minima.* Stunkard and Hinchliffe (1952) exposed canaries, pigeons, gulls and ducklings to cercaria from the mud-snail *Nassa obsolata* and obtained mature specimens of *Austrobilharzia variglan*dis. The cercaria was identified as *C. variglandis* Miller and Northup (1926). The life-history of *A. terrigalensis* was described by Bearup (1956) who reported that the small *Pyrazus australis* served as an intermediate host.

Szidat (1929) described the life-history of *Bilharziella polonica* and reported *Planorbis corneus* and *Limnaea stagnalis* as the intermediate hosts. Porter (1938) found *Physopsis africana* and *Planorbis pfeifferi* also to serve as intermediate hosts of the parasite. Among the species of *Trichobilharzia,* the life-history of *T. yokogawai* was the first to be worked out by Oiso (1927) who found *L. radix* to be the intermediate and ducks the final hosts. The cercaria was described as a pharyngeate, longifurcate form. This is the only instance of a schistosome cercaria described as pharyngeate and it is possible that the muscular posterior portion of the head organ was mistaken for a pharynx. The life-histories of a number of species of this genus have been worked out. The cercariae of all the species show great uniformity in their morphology. They are oculate, with furcal finfold and possess, in naturally emerged state, five pairs of penetration glands and seven pairs of flame cells.

The life-history of none of the species of the subfamily Dendritobilharziinae has been described. But the life-histories of four species of the single genus of Gigantobilharziinae are known, viz. *G. gyrauli, G. sturniae, G. huronensis* and *G. huttoni.*

The life-histories of a comparatively few species of blood-flukes of cold-blooded animals have been elucidated. Of the family Spirorchiidae the life-histories of two species of *Spirorchis,* one each of *Vasotrema* and *Enterohaematotrema* have been worked out. The cercariae are oculate, apharyngeal, brevifurcate with dorsal crest and furcal finfold, possessing six pairs of penetration glands and six pairs of flame cells. *S. parvus* attained maturity in three and a half months (Wall, 1941). In 1951 Wall described the life-history of *V. robustum* and reported that the parasite reached maturity in ten to twelve months. The close similarity in the cercariae of the two genera indicates that the genera *Spirorchis* and *Vasotrema* need not be separated into two subfamilies. The life-histories of only a few species of the family Sanguinicolidae have been worked out although quite a number of cercariae referable to this family have been described. Sanguinicolid cercariae are apharyngeal, brevifurcate, usually oculate monostomes, generally characterised by the presence of a dorsal body crest and furcal finfolds and the absence of flame cells in the tail stem. Wales (1958) has reported that in the cercaria of *S. davisi* and *S. klamathensis* furcal finfolds, and in that of the former species also dorsal crest is absent. There is only one report of the occurrence of redia stages in a sanguinicolid life-history (Wales, 1958). More than half a dozen sanguinicolid cercariae have been described from India but no adults have been traced.

SEX IN SCHISTOSOMES

Blood-flukes of the family Schistosomatidae are dioecious with sexual dimorphism in the adults. The trematodes of all other families are hermaphrodite. Vogel (1947) was the first to report hermaphroditism in an African strain of *Schistosoma mansoni.* The specimens were otherwise males but provided, in addition, with an ovary containing typical egg cells and in some with an oviduct and uterus and vitelline glands. Short (1948), LaGrange and Scheecqmans (1949) and Buttner (1950) also reported hermaphroditism in males of *S. mansoni*. In some of Short's specimens the female component had attained a more advanced stage of development showing a common genital pore produced by the union of the terminal parts of the female and male ducts. Similar hermaphroditism in a male *Schistosoma japonicum* has been reported by Moore (1955). He also reported the presence of supernumerary testes in males of *S. japonicum*. Hermaphroditism in female specimens of *Schistosomatium douthitti* has been reported by Short (1951). No satisfactory explanation of the occurrence of hermaphroditism has been put forward. Vogel (1947) was of the opinion that the transformation of males into hermaphrodites was specially prone to occur in relation to certain species of mammalian hosts such as guinea-pigs, hamsters and rabbits and that the absence of a female partner seemed to influence greater proportion of such hermaphrodites. In none of the instances of hermaphroditism referred to above was the production of viable ova noticed. Hermaphroditism was therefore only structural and not functional.

Parthenogentic development of ova, so rare in the digenetic termatodes, has been reported to occur frequently in the schistosome *Schistosomatium douthitti* by Short (1952). The miracidia developed from such ova were apparently normal in structure and activity and infective to snails. Cercariae derived from such infections were infective for mice. Earlier, Vogel (1942) had suggested that parthenogenetic development of eggs might have occurred in the cross experiment conducted by him between males and females of different species of *Schistosoma*. In these crosses only a few ova produced viable miracidia and the larvae and adults of the F1 generation showed only maternal characters. As suggested by Short (l.c.) the almost normal occurrence of parthenogensis in *Schistosomatium douthitti* may be correlated to the findings that females of *S. douthitti* mature without males, while those of *S. japonicum, S. mansoni,* etc., do not.

While the intrageneric crosses by Vogel (1942) (*S. japonicum, S. mansoni, S. haematobium*) and the intergeneric crosses by Short (1948) (*Schistosoma mansoni* and *Schistosomatium douthitti*) resulted apparently in parthenogenetic development, crosses between two very similar species of *Schistosoma,* viz. *S. mansoni* and *S. rodhaini* by Le Roux (1954) resulted in actual hybridization. The hybrids had the characteristics of *S. mansoni* var. *rodentorum.*

Normally a male schistosome clasps one female in its gynaecophoric canal. However, polygamy among schistosomes occurring in a number of hosts has been recorded by several workers (Price, 1931 ; McIntosh, 1935 ; Evans, Kuntz and Stirewalt, 1949 ; Kuntz, Stirewalt and Evans, 1949 ; Standen, 1949 ; Short, 1952). Males with two or three females in their gynaecophoric canals have been observed. Standen (1949) also reported several instances in which one female was shared by two males. Cases of pairing of males are also known (Short 1952). Chu (1938) from his observations of copulation in *S. japonicum* in-vitro concluded that the copulation in the blood-fluke was a purely reflex action and in the absence of females males took even lifeless bodies into their gynaecophoric canal. Such sexual anomalies occurred when the number of males and females in a host differed considerably. The influence of the presence of schistosomes of both sexes or the absence of one sex on growth and maturity of these worms has been studied by many workers. It has been demonstrated that while the presence of either sex affects the growth and maturity of the other sex in some blood-flukes, in others the presence of only males exerts such influence on the females. But neither the nature of the influence nor the manner in which it is exerted is well known. Vogel (1941) put forth two views: one presumed the presence of hormone which is transferred from worm to worm with sex products or through the integument of the worm but not through the blood of the host, and the other that only when paired could female and also male schistosomes obtain adequate food for normal development. The problem of sex determination has been studied by several workers and it is now well known that sex in the schistosomes is determined in the fertilised egg and all the cercariae developing from a single miracidium are of the same sex. Usually snails harbour unisexual infection but in heavily infected areas naturally infected snails shed cercariae of both sexes. There are, however, no morphological differences to distinguish male and female cercariae. Cytological evidence on whether sex in schistosomes is determined by X-chromosomes is not conclusive.

PARASITE-HOST RELATIONSHIP

The schistosomes show varying degree of definitive-host specificity. *Schistosoma japonicum* has the widest range of infectivity for definitive hosts. It can infect primates, carnivores, ungulates, rodents, insectivores, ets. *S. mansoni* and *S. haematobium* show more rigid host-specificity. Normally, they are able to infect primates and rodents only. Among the Indian species, *S. incognitum* has a very wide range of infectivity. The infection could be established experimentally in cattle, sheep, goat, pig, dog, cat, rabbit, guinea-pig, squirrel, rat and mice. (Sinha and Srivastava, unpublished work). Other Indian species are more host-specific.

The schistosome cercariae possess great invasive power. Even avian schistosome cercariae are able to penetrate mammalian hosts and migrate to the lungs (Olivier, 1953) where they are subsequently killed. Fairley *et al* (1927, 1930) and Kagan (1953) have shown that the cercariae of *S. spindale* and *Schistosomatium douthitti* are able initially to invade the circulatory system of unsuitable hosts also. It is most likely that other schistosome cercariae are also able to do so. As pointed out by Kagan (1958) an innate immunity is probably associated with the subsequent death of the parasites in such hosts. Whether the actual mechanism for such destruction of the parasite is an active cellular response alone or some specific antibody or a non-specific response such as an increase in the properdin level of the host-serum is also associated, is not yet definitely known.

In the normal host the longevity of the parasite is probably quite high. *S. haematobium* may live upto 20 years or more in man (Berberian, *et al*, 1953). But spontaneous disappearance of the parasites from infected normal hosts also frequently occurs. Acquired immunity against schistosomes in animals has been reported by several workers (Fairley, 1926; Kagan, 1952, 1953; Stirewalt, 1953; Vogel and Minning, 1953; Meleney and Moore, 1954; Hunter, *et al*, 1956). In rodents this appears to be only a state of premunition—necessitating the presence of an active infection to maintain and stimulate immunity. In monkeys, however, the acquired immunity lasts even after the animal is free of the previous infections.

BIOLOGY AND SUSCEPTIBILITY OF MOLLUSCAN HOSTS

Researches on schistosomiasis have stimulated studies on the various aspects of the molluscan intermediate hosts. Much work has been done on the biology of the molluscan vectors of *S. japonicum, S. mansoni* and *S. haematobium,* but much more remains to be done. In particular, the taxonomy of the molluscs concerned in the transmission of schistosome infection in Africa needs careful study. In India, almost no work has been done on the biology of the molluscan hosts of blood-flukes. And this provides a rich field of fruitful research for the Indian Zoologists working on Molluscs. Their researches will not only furnish valuable data of zoological interest but will also provide the Applied Helminthologists with information on many important aspects which are so badly needed.

Studies on the susceptibility of the molluscan intermediate hosts to infection by *Schistosoma mansoni* have revealed the existence of physiological differences between the strains of the parasite from the different geographical regions and of inter-specific and intra-specific physiological differences between the intermediate hosts. Such differences have been reported between the strains of *S. mansoni* from Puerto Rico, Venezuela, Surinam, Brazil and Egypt ; between *Australorbis glabratus* from Brazil and that from Puerto Rico, Venezuela, Surinam, etc., and between *A. glabratus* from these regions and *Biomphalaria pfeifferi* from Liberia and *B. boissyi* from Egypt (Files and Cram, 1949 ; Files, 1951). Further, the intra-specific physiological difference in the susceptibility of *A. glabratus* to infection by *S. mansoni* has been reported to be a genetically determined character (Newton, 1953).

Within the limit of a presidential address it has not been possible to refer to all the valuable work which has been done in different countries on the various aspects of blood-flukes, particularly on the larval forms. However, some of the aspects of the problem of mammalian schistosomes in India on which further work is indicated are : (1) Suspectibility of natural and experimental definitive hosts and the factors influencing it, (2) Hybridisation of the different species, (3) Histo-chemical and physiological studies, (4) Biology of the schistosomes affecting man at Gimbvi, (5) Zoonosis and (6) Ecology of intermediate hosts and the factors influencing their distribution. The avian schistosome fauna of India remains largely unexplored. A study of this group is necessary not only from the zoological standpoint but also because their cercariae may be involved in the causation of dermatitis in agricultural and fishing population. Except for *Enterohaematotrema palaeorticum,* the life-histories of the blood-flukes of cold-blooded animals have not been studied in India. The sanguinicolids may be quite pathogenic to fishes (Wales, 1958) and studies on their biology should be initiated. More than half a dozen cercariae of this group have been described from this country but the adult of none of them has been traced.

Before concluding, I should like to express my thanks to the members of the Sectional Committee of Zoology and Entomology for electing me to preside over this Section.

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SECTION OF ANTHROPOLOGY & ARCHAEOLOGY

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PLACE OF NUTRITION IN THE GROWTH OF MAN.

Anthropology, the science of man in its modern sense embraces a wide field. Not only the science now deals with the origin of man but also his progress in various walks of life, the cultural aspect like the art of agriculture, metallurgy, material culture, ethnology, ethnography etc., and in this way everything in relation to man within reasonable limit. Anthropology with its extended arms like Genetics, Eugenics etc., has also to engage not without reason its attention for the better type of people, better not only in the sense of physical health but also intellectually and in culture. Individuals are but the makers of nation. Hence the individual need be very good so that a nation becomes good and prosperous. 'Fellowship between nations and peoples is a distinct object still'[1]. It is all the more necessary therefore that the individual must grow in such a way that all these qualities obtain opportunity to develop. This is how people can be happy and the human relation becomes sweeter and congenial. This is the aim of mankind. Science must contribute its might towards this.

Anthropology has much to contribute to this direction by growing good people on the earth. Social science has made some progress in controlling births and if anthropology offers its helping hand social science can help in the growth only of desirable births and in weeding out the undesirable, imbecile and other social evils thus starting a new era of perfect nation. Morant[2] in 1939 said that " the main aim of physical anthropology is to unravel the course of human evolution and it may be taken for granted today that the proper study of natural descent of man is concerned essentially with the mode and path of his descent ". It is in this way that this world of ours can be converted into an abode of happiness and peace i.e. the theme is " Building tomorrow today ".

As said above, an individual is the index of a nation. Let us think of an individual. Even in the early period when the individual is only an unsegmented fertilised ovum, when there has taken place no differentiation, there is something in each individual of the species which determines its characteristic development in both physical aspect concerned with the structure of cells, tissues and organs and their chemical aspects namely the enzymes and the specific secretions. After birth he passes through many phases in matters of growth, in matter of food, in matter of education, psycho-social relations etc., until he becomes old and dies. Developments thus taking place right from the moment of inception of a new life as a zygote formed by fusion of gametes from the parents and the organism thus brought into being presents a series of organisations which are in continual change as age advances and in the absence of accident or mishaps proceeding upto his death. This is called life cycle, Gillman and Gillman call the same, life track.[3] More explicitly, the term carries a sense of all the events taken together that take place in the life of an individual from fertilisation to death through senescence. There is the end of life track. Every individual follows a particular life track. Nervous system and endocrine gland, are generally held responsible for any type of development that occurs in the life of an individual.

But growth continues in the embryo long before development and differentiation of organs and just as for example, before any organ that is known to participate in metabolism, say protein, in adult, have come into its independent existence, protein metabolism proceeds. Question thus naturally arises how in the embryonic stage when nervous systems and endocrines have not yet been differentiated into independent existence, developments can proceed? Mystery, however, remains still unveiled. Not to speak of the nervous system and endocrines helping growth of others, they themselves will not grow without the help of those for whose growth they evolved. Mutual help is necessary. This shows that the organism is an integrated whole in which any one change in one organ produces invariable change in the other. Thus when there is less blood sugar, there is less liberation of insulin by the islet tissue and there is correspondingly less muscular activity. This peculiarity continues from initiation of life as aging proceeds until death, whether they are within the body, the internal constancy under vegetative nervous system or outside, the psycho-social behaviour. At different period of life the individual presents different patterns which are the resultants of innumerable number of regulations—physiological regulations which include physical and chemical regulations accompanied with numerous control system maintaining all throughout a very rigid dynamic equilibrium. Conception about the make-up of human body was, of course, at one time supposed to be like a machine composed of different parts representing liver, spleen, heart, lungs, etc., in the human system. The machine concept of human organism does not receive support from many, to me—it is far from that. On the contrary, it is a highly dynamic as well as highly integrated mutually controlled organism and not like a machine ; for mere replacement of part of organ cannot maintain the normal health of the individual as is feasible in a machine. Individual thus appears like a mosaic of many tissues and organs each one functioning and performing its own metabolism in its own specific way but at the same time in an intimately integrated manner just like " Co-operative Plan ". This mosaic of separate parts in the individual may be considered as biological basis of individuality.

Claude Bernard[4] wrote about eighty years ago that " analysis, which teaches us the properties of isolated elementary parts, can never give more than a most incomplete ideal synthesis, just as knowing a solitary man would not bring us knowledge of all the institutions which result from man's association and which can reveals themselves only through social life. In a word, when we unite physiological elements we must therefore always proceed experimentally in vital synthesis, because quite characteristic phenomena may result from more and more complex union or association of organised elements. All these prove that these elements, though distinct and self-dependent, do not therefore play the part of simple associates, their union expresses more than the addition of their separate properties. The regulation in a particular stage of development determines to a considerable extent regulation in the next succeeding stages in the life cycle of the individual unless this i.e. if the development at a particular stage does not depend on the development of its previous stage, the life cycle of the individual cannot proceed steadily with consistency and smoothness. This is perhaps because even the tissue protein alters in age as recorded by Ruzicka in 1924[5]. Waddington in 1938[6] removed Wolffian duct on one side of a chick. This removal interfered with the subsequent development of mesonepheric tubule and also with the development of the Mullerian duct on the other side. In fact, in biological system the continuity of processes along with the change in pattern of regulations throughout the life time is the most important feature, an inescapable event, the open secret of life.

GENES

Life track commences from the moment of zygote formation from the male and female gametes. These gametes carry with them the parental traits. Botanist Naegeli[7] was the first to conceive of a substance peculiar to each individual responsible for carrying parental traits and transmissible from generation to generation and he thought that it is distinct from other less important constituents of the living matter. He gave the name to this highly organised substance " Idioplasm " which is now known as gene gathering round it lots of significance, an old friend in a new name. Genes occupy definite positions in the chromosomes called loci and thus produce a chromosome. Genes are responsible for operating myraid of regulations at every level in the life of a man. The regulations are highly integrated and delicately balanced and are responsible for maintaining the dynamic equilibrium. In fact, genes obtained from parents are all in all, they are the basis, they determine how the offspring will appear, develop and thrive in the world and will perish. So it will not be too much to say that destiny of an individual is principally fixed during conception, i.e. at the time the zygote formation.

With no intention to challenge the view on the mechanism of transmission of hereditary traits, by genes or plasmagenes or by something else yet not known it is universally admitted that the function of the genetic factors is to engineer the regulations which constitute life process.

Genes are responsible for shape and size of the body, also for the inner qualities of head and heart in the offspring, i.e. for both physical and mental structure. It is not yet known clearly why a cow takes the shape of a cow and a sheep grazing in the same field forms into a shape different from that of a cow and also why inspite of the fact that both of them are having adequate food do not continually increase in size upto death but stop attaining any further increase in size at a particular time ; again another still striking peculiarity is noticed in collection of fat by ' dumba ' (Ovis—Sp) in its tail, and development of steatopygia among the Hottentot women. No answer is available why other sheep and other women do not develop those peculiarities. It is also noticed that a particuliar type of cell, e.g. nerve, is very rich in lipids and the nerve tissue performs very exquisitely superior and precise functions, namely, bringing the different part of the body into a functional connection full of harmony and integrity by setting numerous and intricate net-work of nerves and control system whereas the muscle cells which do not acquire lipid but another chemical perform the function of contraction and relaxation thus executing the will of the nerve cells.

This capacity of one cell to acquire lipid, viz., nerve cell and another cell a different chemical (contractile element, i.e. muscle) and consequent difference in function performed by them primarily depends on genes ;

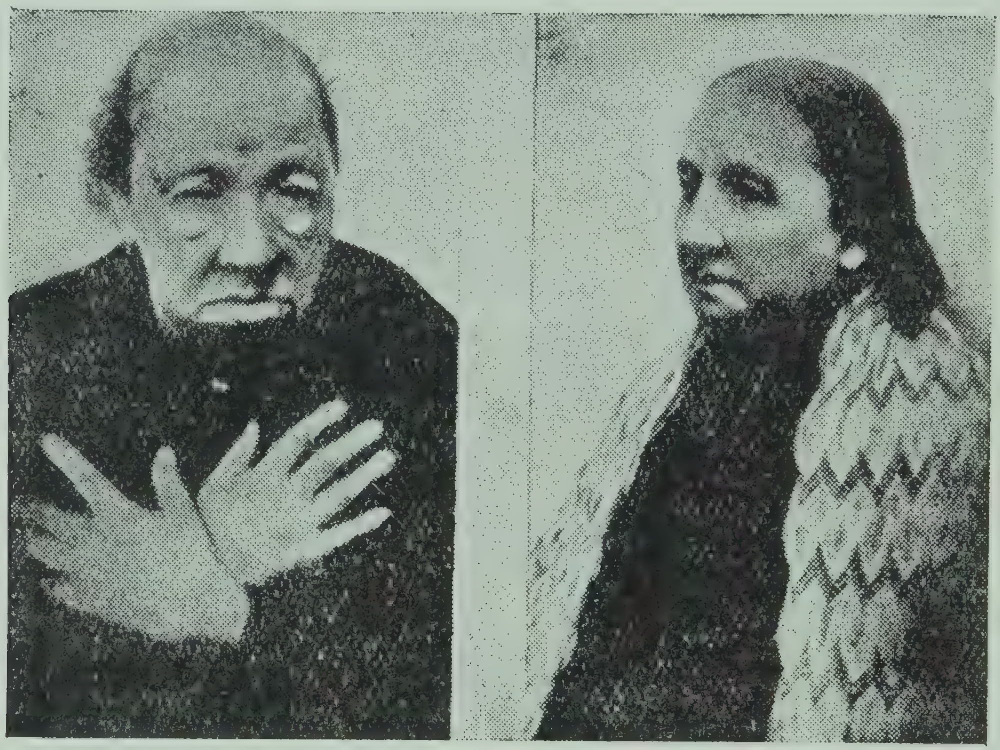
similarly, other peculiarities as stated above. The power of utilisation of different materials by different cells—again varies according to age, e.g. an endocrine, testis utilises more materials for manufacturing its hormones, testosterone in adult stage than in childhood.

HORMONE

Hormone plays some significant role in such a matter as well. It is so complex that our wit is at its end. Frontier of knowledge must extend to understand the way of their working. Hormones are the products of certain specific cells. These products regulate, control, stimulate or inhibit other structure or function. Even in those earlier days when differentiation of blastocyst has not even occurred and the name, hormone should not receive adequate justification for its use, organiser, evocator in fact, themselves actually await the specific secretion for execution of their function. Needham in 1942[8] visualised development as representing a series of successive decisions regarding the facts of parts mediated by a succession of organiser or evocators, chemical substances acting as morphogenetic hormones and he went so deep that he said in his " Order of Life "[9] that ' problem of organisation is the central problem of biology . . . . the riddle of form is the fundamental riddle '.

True, the name hormone cannot rightly be applied there because of no differentiation yet but the determinants work up the chemo-differentiation with the help of the organ or tissue specific substances representing the future hormones. It has been found that salmander embryo deprived of certain part known as 'individuation field' does not attain their usual growth. On the other hand, the dorsal lip of the blastopore of one species of larval amphibia (Triton cristatus) when implanted into another species (Triton taeniatus) the transplanted portion grew into a secondary embryo. Even the various process helping development such as digestion, absorption or ultilisation of food materials cannot function for want of hormone like secretin, corticoids and insulin respectively as can be easily made out from cases of hyperthyroidism and in pituitary hypofunction. Hormones again even regulate their own growth, examples may be obtained in the pituitary stimulating growth of testis, growth of thyroid and so on. Similar such instances are too many to cite. Hormones are so powerful that they are capable of changing an individual's life altogether. It will thus be seen that right from the beginning of a new life in a zygote, much before any significant development has taken place, not to speak of differentiation and upto death, the specific secretion of some cells, the premonitors of future endocrines is quite active. In different sites they show variation in their chemical nature and in physiological properties but they all rigidly and faithfully subserve one common cause and follow one common principle. They exhibit their activity in a wonderful manner not easy to follow in every sphere of life both within the body in the maintenance of internal constancy looking after welfare of the organs and helping them in carrying on their respective and legitimate functions and outside the body in the psycho-social atmosphere. They excite the desire for food, called appetite as a response of which there is ingestion of food, its digestion, absorption and assimilation which aids new addition to what existed from before i.e. helping in growth and then throwing out the unused portions of what was ingested. They excite the desire called thirst, as a response to which one drinks water, which help in the equitable distribution of nutritives to the numerous body cells for their nourishment and also in the washing out and elimination of metabolites from the body.

The excite desire as a response to which there is search for friend followed by procreation of new life. In short, they are indispensable for maintaining all round state of nutrition. In this way hormones take incorporate part in the individual's life. In fact, when nervous system has not evolved, the endocrines were in charge of supreme control of the body and regulation of life process. Best illustration of their phenomenal powerful activity will be found in the life of a female. Between menarche and monopause she is entirely a different individual in body and mind from what she is before menarche and after menopause. Their influence can be adequately judged when a healthy individual is compared to one whose thyroid or adrenal cortex is diseased. All these peculiarities owe their origin to whims of hormones. Here is an instance of the whims of thyroid gland (diagram below)



Myxeedema treated with thyroid, taken from
S. Wright, 9th Ed. 1952

The cause of all these development is to be sought mainly in the germ cell. It is so very characteristic with such great potentiality. The individual twining plants behave differently ' chupri aloo ' (dioscorea) ascends coiling towards right or clockwise whereas shim (dolichos) coil towards left, sinistrorse or anticlockwise. Such remarkable similarity and specificity can only be explained by properties residing in the genes. "Every stage in development represents the materials and physiological realisation of the specific attributes of each species"[3a]. The specificities or characteristics of the particular species are not acquired all on a sudden by the individual, man or other mammals or any other animal. The acquirement is gradual, the genes in the ovum and the genes in the sperm determine everything in the organism, the enzyme action, specific composition of the protein in the tissue, the way of the food is utilised and morphological and physiological properties, psycho-social behaviour at all stages of development.

Genes are primarily responsible for all these. It is not my intention to discuss different aspects of heredity but to throw some light on the importance of genes in the chromosomes, which is universally admitted to play a vital role in heredity. Genes start the show, they are the sources of energy. As they generate energy they themselves not only become richer in energy content like a dynamo but the energy radiates outside too, makes the outward more beautiful and agreeable in look. The sun is the sourse of light and when a beam of the sun light passes through a prism, it breaks into a beautiful spectrum of colours. So also the genes are the source, the momentrum, and the outward show thus created forms the spectrum, namely, the individuals with their characteristics as we see in the societies or to put in different way i.e. momentum is the genotype while phenotype is the spectrum. In the spectrum of sun-rays there are seven colours, in the same way in the spectrum of phenotype there is a vast array of patterns, patterns in shape, size, mental structure, intellectual manifestation, and different qualities like sympathy, kindness, compassion etc., or patterns of crookedness, selfishness, vanity, inclination to immoral activities, cruelty and similar other vices. All the attributes of man are established from a genotype depending on the nature of genes concerned. If the genes are good, the zygote containing those genes become the potential source, the momentum of development of an ideal individual, correspondingly the phenotype develops with enormous capabilities to be useful to the world. On the contrary, if the genes are bad the phenotype (spectrum) grown will be a bad individual, may be criminal or wicked. In this way fertilised ovum if it contains good genes it constitutes a depository of good and vast array of patterns of human characters ; numerous beautiful spectra, as it were, would develop after coming in contact with the suitable type of environment, which serve as stimulii. The individual thus born will exhibit enviable qualities and endowment that can transform this world from hatred, and mistrust into an abode sublime and elegant. Really there is unlimited scope for the individual to go to any extent either towards good if genes are good or towards bad if genes are bad. In actual field realisation of vast potentiality is of course frequently much narrowed in the world because of the influence of environment on the genotype. This is why growth is often met with in somewhat restricted form. Nevertheless, the constitution is so set up that under all condition of health an equilibrium is maintained within the cells just a milieu interieur for the whole body and development proceeds at the usual rate which is fixed for a definite species viz., the cow as said before has definite period to grow, definite size to attain beyond which no matter how much nourishment may be supplied, there is no increase in size. Thus for an individual to grow both physically and mentally the role of the genes is undoubtedly exceedingly enormous. Some light, dim though has been thrown on the role played by the genes but the picture will not be complete unless something is said about environmental factors.

ENVIRONMENT

Environment is next important upon which genes primarily depend for their formation. Environment like temperature, light radiation, humidity, atmospheric pressure etc., have tremendous influence on growth. In extremes of the above mentioned conditions even death may occur ; on the contrary, when they are within reasonable limits and optimum, they help substantially in the growth i.e. increase in bulk and help in differentiation i.e. elaboration of new parts over what existed previously. Those two vital aspects of an organism are apparently regulated by diet and environment, of course, under the remote influence of genes. If the environment is beyond these extremes, notwithstanding the enormous flexibility and adaptibility of the biological system diet alone can not help, the regulation is invariably disturbed. Unfavourable environment does not even permit proper utilization of food. Bonsma[10] in 1940 recorded that stunting of cattle once produced by temperature can not be corrected by diet. He further showed that animal which can grow actively in one environment on a particular diet, stop growing in adverse environment, even when the same diet is fortified with good protein. Similarly[11] when human ponies emigrate out in a favourable environment in the United States they only require two generations to produce descendents with significant increase in stature by several inches.

Thus the various types of environmental influence like climate etc., either collectively or individually modify metabolism, the physiological regulations. Diet rather instead of doing good may cause more harm if environment is not congenial e.g. when a man takes good food but can not digest owing to uncongenial environment, there is indigestion and diarrhoea which produce damage to the system, for indigestion, diarrhoea produce depletion of more water from the body, whereas accumulation of water and of other metabolites takes place in constipation. Both of these invariably cause disturbance in metabolism affecting growth. It is often seen that individual who suffered from indigestion or diarrhoea in infancy or childhood cannot usually reach the health standard even in adolescence. The life track itself of an individual is thus the resultant of impact of environment on genes.

As this environment question is not the issue of to-day's talk it will not be pursued any more and attention will be diverted to another similar factor, perhaps more important namely, the diet which has a dominant action in the formation of genes responsible for the phenotype. The ovum when it is fertilised becomes enormously endowed with the vast potentiality of growing through successive development in due course during life.

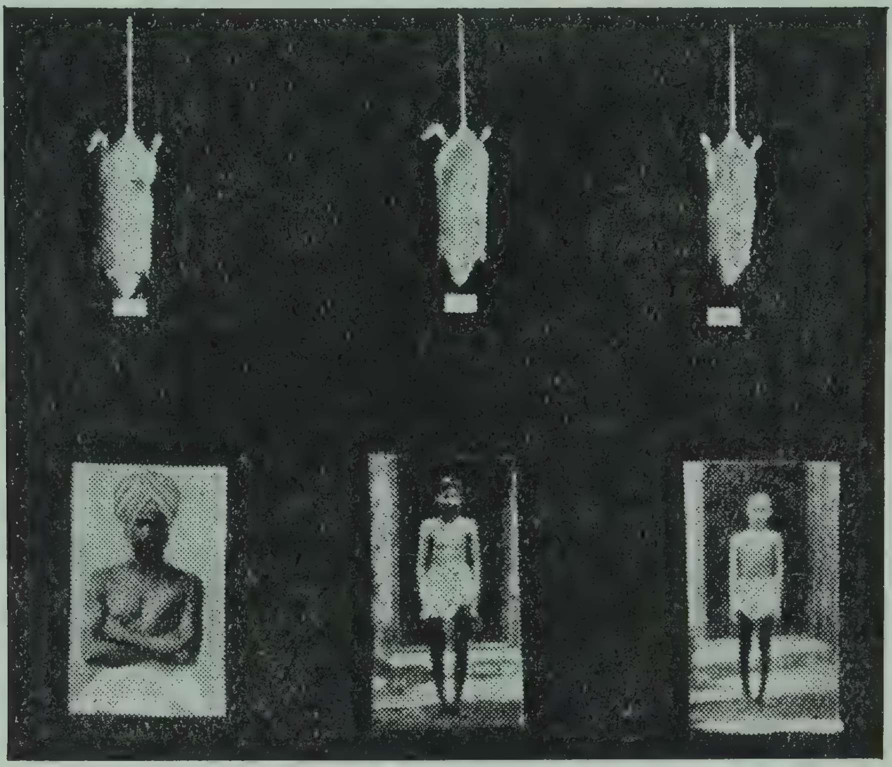
Development proceeds from the moment of fertilization through different stages and in every stage the development depends not only on the available diet providing aliment and nutrients which are responsible for maintaining proper nutriture but also to suitable environment. In fact, like environment, diet undoubtedly exercises remarkable influence on the growth.

Genes have vast, varied and miraculous power no doubt, but the food is essential there too. Food will furnish material and at the same time energy necessary for the genes to effect growth and differentiation. From food one obtains functional proteins, the enzymes. The enzymes are responsible for the function of mobilishing energy from the proximate principles of food—the carbohydrate, fat, or protein. When these enzymes are not available, utilisation of food is not possible. Thus in certain individual because of congenital absence of enzymes no final metabolism of tyrosine is possible. Consequently, there is accumulation of the intermediate products, dioxyphenyl acetic acid in blood and its ultimate elimination in the urine, a condition known as "Alkaptonuria". Food also supplies structural protein which actually adds fresh materials appropriate to the individual. For example, a man takes a foreign fat. This fat after entering the system gradually becomes transformed through activity of enzymes into material specific to his own body i.e. constituents of human body. Laboratory experiments prove that lard having melting point 63°C when ingested by rats in large amount gets transformed into body fat peculiar to the species having melting point 71°C, of course, the process of transformation proceeds gradually. This is a well known fact utilised in farm for raising stock. Food has thus a remarkable influence.

Again if a particular item necessary for growth is not supplied during growth period, body undoubtedly suffers from usual growth dependent on that particular item. System, however, tries to make up the particular substance in the system at the cost of the materials already obtained. This does harm. For example, if a high fatty food is given to an animal, say rat, the gastrointestinal tract will elaborate only fat-splitting enzyme which will help digestion of fat, its absorption and will produce lipaemia and ketosis. If high protein diet is given to rat in place of fat, pancreatic tissues contain large amount of trypsin and only small amount of amylase. Thus it will be seen that the usually large quantity of fat or protein not only stands on the way of elaborating enzymes other than those required for digestion of the stuff ingested and interfere with the digestion of other stuff, but they lead to excessive absorption of fat or protein, production of large amount of acids, hydroxybutyric acid—acetoacetic acid etc., with consequent alteration chemical and physical composition of blood which disturbs the metabolism and which may even usher in death by coma. This is not the full picture, other consequences may follow as well. Thus excess fat, while undergoing oxidation gives rise to water. This water requires elimination, otherwise internal constancy will not be maintained. Elimination of excess water demands the service of kidney. Kidney drags pituitary, thyroid, cardiovascular system and other organs into the picture for its legitimate function of elimination of water. It is not an easy task to bring all the organs into a functional harmony. It involves expenditure of energy. It follows then that to correct a simple disturbance caused by ingestion in excess of a particular food material, here fat, so much labour has to be put in at the cost of enormous energy. This shows that all that is necessary is to maintain the stage of nutriture by a balance diet when all these disturbances can not occur. Nutriture or state of nutrition, maintained by a balanced diet will then determine the type of regulation necessary for the system to restore the metabolism and to establish normal equilibrium. Shetland ponies from the dwarf size owing to under-nutrition grow into usual size of their ancestors, the English horses even after one hundred generations when placed on good food and congenial environment. De Castro quotes the anthropologist, Torday who recorded his observation that the pygmies of equatorial Africa lose their pygmy characters when transplanted to the plains where better food was available. Thus, it must be fully realised to subserve the object of science, that for rate of growth and differentiation, which ultimately principally depends on the nutritional level, nutriture must be maintained at par. Nutritional level, however, is not the same all throughout the development period. What he finds adequate when just born—he finds quite unsuitable in adolescence or senesence, what he needs during fertilization—he requires different even in the different stages of intrauterine life e.g. gastrula, neurula, embryo, foetus and just born—which is markedly different from what he receives later during his post natal and adult period.

Even nutriture of the mother both before and after fertilisation—exerts remarkable influence on the growth of the body. A baby born of a mother suffering from malnutrition was found a victim to ricket and other maladies. Korenchevsky[12] in 1922 recorded that a baby born of a mother suffering from malnutrition had ricket inspite of being fed with breast milk by a normal mother—whose own baby had no such calamity. Toverud & Toverud (1933)[13], Jackson (1925)[14] quote similar instance illustrating the same fact. The nutrition state during pregnancy thus materially set up nutrition requirement after the birth of infant in his post natal life.

Simple laboraroty experiments yield identical results. Having maintained all other condition like animals of same litter, of same age, under similar environment etc. variation in diet produced remarkable difference in the attainment of growth. Mc Carrison [11a] recorded a weight of 255 gm. for a rat on Sikh diet whereas only 155 gm. on Madrasi diet (diagram below).



Note the fibre Physique of Sikh on the well constituted diet and Bengali and Madrasi whose diets are ill constituted. Similar effects on rats fed on similar diets from left to right.
From Nutrition and Health by McCarrison, R. & Sinclair H. M. Faber & Faber, London.

Lord Boyd Orr and Gilks[11b] recorded similar observation after their elaborate study on the Kikuyu tribes living principally on cereals, tubers, etc., and the Masai tribes, the cattleraisers whose diet consists of meat, milk even animal blood. Both the tribes live side by side under same natural environment and climate in East Africa. The Masai men are taller by three inches and heavier by 27 lbs. than their neighbours, the Kikuyu and so also the Zulu.

Nutrition therefore is a crucial factor for determining the phenotype. It was rightly said by the general Medical Profession in U.K. in response to an appeal by German Medical Profession in post war-period, that "this existing chronic under nourishment has already produced an advanced reduction of physical substances and has not only extremely diminished the German Physical efficiency but has also adversely affected his intellectual power and altered his emotional structure"[11c]. A starving man is deprived of initiative, he is irritable, hypercritical and incapable of both constructive work and discharging his public duties. There is mental apathy, moral deterioration, depressive maniac inclination, tendency towards introversion, change is personality, lowered intellectual capabilities. True, "the brain is in some sort of custody of the stomach and relief of malnutrition gives relief of mental dulness"[15]

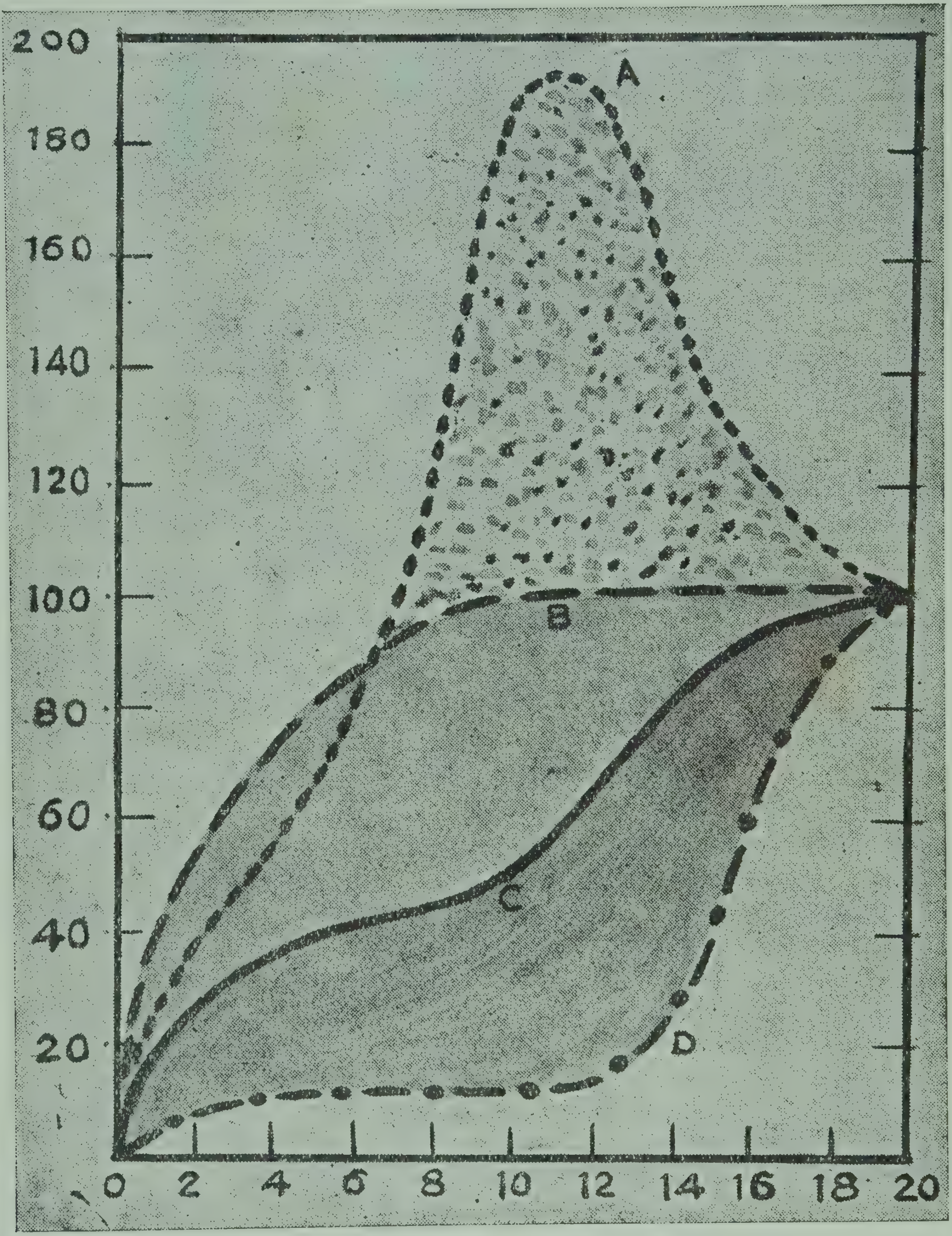
On the other hand, if adequate food be available, the genes those are concerned in inception of a new life, are likely to be formed in the best possible state and consequently stimulate continual progress in growth in the individual.

Look at the Java man in those remote days—upper Pliocence, who did not know even the use of fire or use of made-up tools. The next, Sinanthropus pekinensis although almost contemporary acquired the knowledge not only of the use of fire but also exhibited evidence of using worked flints. The skull of the pithecanthropus presents just a rudimentary frontal eminence, whereas that of the sinanthropus pekinensis presents definite frontal and parietal eminences. Necessarily, the development of those parts of the brain needed material which as it appears, was plentifully available in those remote days when they grew and progressed. Man thus could make very rapid and substantial progress and consequently it is found in a comparatively short space of time enormous advance and culture in succession as Chellean, Mousterian, Aurignacian, Magdalenian and so on. All these go to lend evidence how much of food both good and adequate is necessary for the development of better brain and in turn, better man.

If science does not come forward to cope with the situation regarding state of nutrition which is much below at present than what is considered ideal, optimum, world will be dominated by people lacking the qualities that entitle an individual to be labelled as man and disastrous results—mistrust, suspicion, want of drive for moral uplift etc., will prevail, world can not be happier—can not be a seat of peace and sobriety. "Life is quality and not quantity". Rightly the great philosopher Bertrand Russel said "there was never a moment in history when contribution of individual thought and conscience was so necessary and important for the world as it is in our days" and he further continued that "all man, any man at all, can contribute to the betterment of the world"[16]. Appropriately, the League of Nations said in 1927[17] "the application of modern knowledge on nutrition is opening up entirely new perspective for the improvement of human welfare". It is rightly said "without measures that will ensure the better feeding of the people they cannot like a diet inadequate in vitamins though complete in other regards, achieve the end in view—'the building of All nation'.[17] Unless the people concerned are not socially and traditionally biased, the importance of nutrition in building a nation, should not be under-rated.

Gravity of the problem of nutrition seems not to have received as much attention as it deserves. Of course, there are various reasons for this but it is also high time that the problem should receive due recognition, its seriousness should be thoroughly appraised and a scale of nutrition established. Then only people can enjoy a sense of security and feel contented. Inspite of the vigorous attempts at the cost of money and mind from almost every corner of the world for peace, the aim is being hardly achieved. Reasons thereof although not easy to trace, there seems at least one reason agreed and that is difference in the perspective, difference in the angle of vision with which one looks at peace and contentment which is the desideratum of mankind. To achieve this all that is necessary is health as defined by the World Health Organisation and to obtain such health proper nutrition is imperative. Over two thousand years ago, Hippocrates wrote[18a] "it appears to me necessary to every physician to be skilled in nature and to strive to know, if he would wish to perform his duties what a man is in relation to the articles of food and drink and to his other occupations and what are to every one".

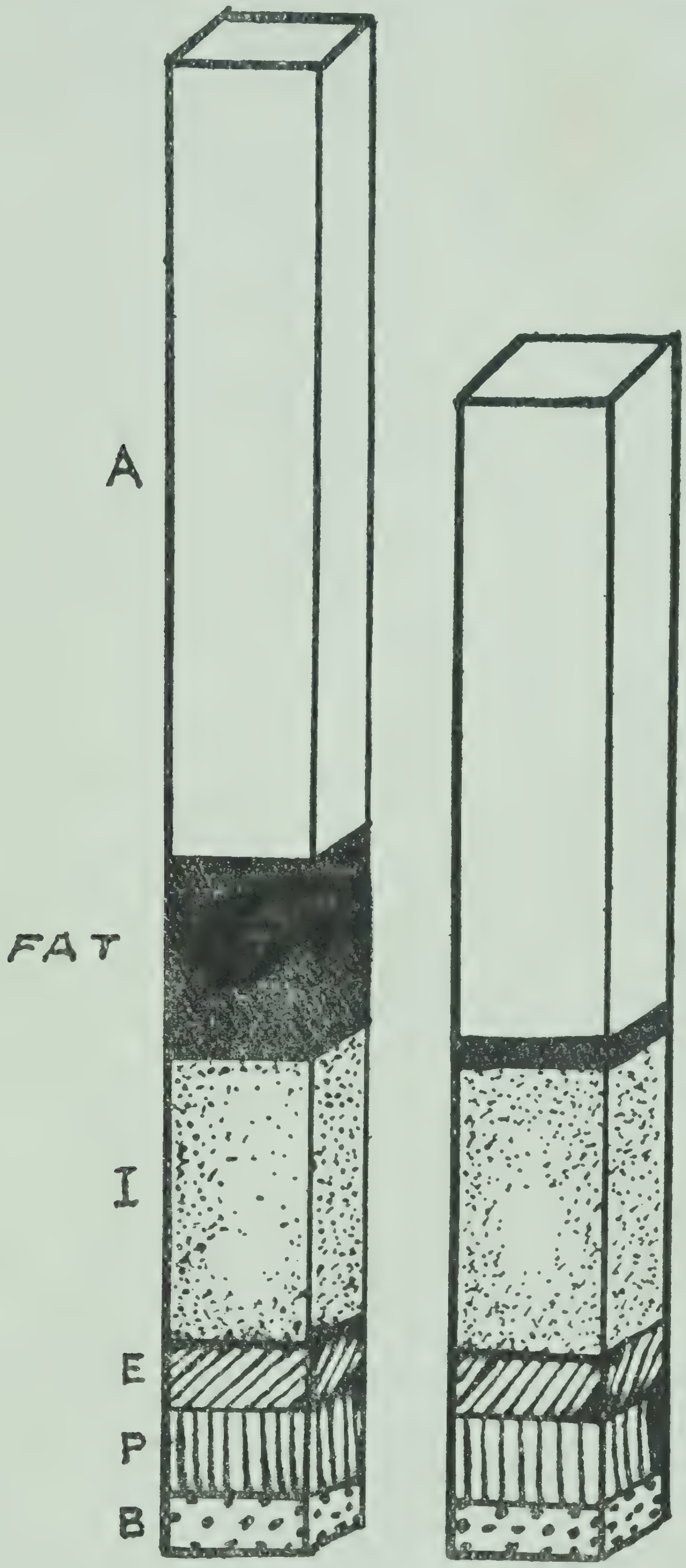
In order to grow this type of people, much desired as indicated above, nutrition must be supplied in adequate amount both in quality and quantity in different milestones of life because the different tissue of the body grow at different rate at different period. Looking below at the diagram, it will be seen that the nervous system takes a rapid stride when other systems wriggle and lag behind. Thus when a baby is born, his brain constitutes 12 to 15% of the total body weight. As age advances, other parts grow at higher rate than the rate at which nervous system grows, as a result, the brain forms only 3% in adult. The diagram shows also that nervous system starts growing early, advances early and completes its growth early, only at about 6 years of age—when other systems virtually start growing. The exceedingly rapid rate of growth of the nervous system can be still more appreciated from the facts when the baby is born his brain weighs 150 gm., in the 3rd month it is 530 gm., 6th month



Growth curves of different types of organs. (white house reports, 1932).
A. Lymphoid Type.
B. Neural Type.
G. General Type.
D. Reproductive Type.

785 gm., 1st year 930 gm., 2nd year 1000 gm., 3rd year 1150 gm., 6th year 1200 gm., while the adult brain weighs 3000 gm. In intrauterine life the rate of growth is still higher. This will convince one how very important it is to supply appropriate material in adequate amount for the development of the nervous system even in that early period of growth.

The gravity of the problem can also be appreciated from another angle. Different organs of an individual placed on under-nutrition suffer loss of weight to different extent. This is significant showing



The weights of the major compartments of the body of young men in normal nutrition, on left; after 24 weeks of semi-starvation, on right; A, active tissue (total body weight less the other indicated compartments); B, bone mineral; E. Erythrocytes; I, interstitial fluid, (thiocyanate space less plasma volume); from Keys and Associates, the Biology of Human Starvation, University of Minnesota Press, redrawn and modified.

importance of particular organ over others. Thus although the body suffers from 50% of total loss in body weight—he has lost only 3% weight of his heart and brain, whereas muscles lose 30% and liver 55%. The following diagram will illustrate the peculiar feature developed after placing a man in under-nutrition for 6 months (diagram overleaf).

It is very clear from the diagram that there has been loss in body weight but when analysed it will be perceived that all the body materials are not affected in the loss equally—loss of fat is quite high but even bone is not an exception. Protein is lost only to a minor degree e.g. heart loses only 0·5% protein. This is why the individual is a victim to loss in varying degree thus showing varieties of disorder, which is not easy to detect and to label symptoms of under-nutrition from any particular item. A general clinician will invariably commit mistake unless he is familiar with the diverse picture, malnutrition can produce. To make the task lighter symptoms of under-nutrition may be grouped into three big groups (I) well known fact (e.g. emaciation, reduced body weight, sunken eyes, dry pinches faces, weakness, lack of enthusiasm, easy fatiguability on exertion etc. (II) ill-appreciated facts—in the course of our[19, 20, 21] own investigation on ill-nourished subjects individual frequently exhibited symptoms of dysentery. This is due to friction of intestinal mucosa and thereby expulsion of mucus or/and blood although the subject was not really a victim of any pathogenic organism. Mc. Carrison[22] described that mal-nourished monkeys fell easy victim to amoebic infection and he opined that normal intestinal flora may turn pathogenic leading to severe ulcerative colitis in mal-nourished individual. Thus many symptoms caused by infection gives impression of nerve disease such as incoherence, tremors as in thyrotoxicosis etc. Intestinal infection may secondarily damage liver producing hepatic insufficiency, cirrhosis etc. The real cause however, as far from that. Inanition may produce symptoms stimulating hypophysectomy[23]. It is nothing but a true case of under-malnutrition and (III) little known facts—such as sterility, undescended testis, gynaecomastia, pyosalphinx, positive Wassermann reaction etc. Similarly, Phrynoderma[24] Comedones may appear[25].

From every direction it is now felt that nutrition is essential in modifying the individual in every stage. Right from the stage of genes formation which is constituted from nucleoprotein adequate nutrition is imperative and indispensable if a suitable strain of life is intended.

Nucleoprotein which constitutes genes is a class of substance distinct from other charged with highly organised properties in the make-up of which enter proteins specially the first class protein obtained from outside. First class proteins are those in which nearly all the (indispensable) aminoacids are represented and which contain these aminoacids in proportion approximating the average of those found in the chief tissue proteins. To prepare good genes, good nucleoproteins are necessary. Good nucleoproteins can be readily found from first class proteins. In case, good nucleoproteins can be formed, the chromosomes made of genes will be ideal type and the genotypes constituted by these chromosomes will be ideal with corresponding ideal phenotype subject to healthy and congenial environment. An analogy may be drawn between a chromosome and a harmonium in which the reeds are genes. A harmonium is good, if the reeds are good and well placed. Then it gives out melodies. A mosaic is appealing to eyes if the constituent colours and textiles are themselves good and suitably placed. In the harmonium and mosaic man can place the reeds and colourful textiles according to his choice and can make better from good, but in the preparation of chromosomes there is no force known which can select the suitable genes and can determine suitable loci for the genes in the formation of chromosomes. Here it is entirely a question of chance. Man can claim no knowledge for selecting and setting the genes for the formation of a good chromosome.

Again, take for instance three letters D.G.O. These three letters apart from their intrinsic worth, if there be any, if suitably placed, they give rise to 'GOD', if next best placed, they give rise to 'DOG', whereas placed in the third way, they mean nothing 'OGD'. In the same way the genes must be intrinsically good, and must be suitably placed so as to constitute the best type of chromosomes which in turn will produce best type of people. Since in the former two operations, namely, selecting genes and assigning the genes proper locus in the formation of chromosomes, man has no control, hence it is felt all the more pertinent to help in the formation of best genes out of the best nucleoprotein which can be made available by supplying the best protein from outside. So in the formation of good type of people to make the world happier, all that man can do is to supply first class protein. It has to be remembered that a temple can be made out of bricks obtained from demolition of a mosque or a church and vice versa. Thanks to the Dutch chemist Mulder who gave the name *protein* in 1839 to the universal component of tissue both plant and animal, "unquestionably the most important of all known substances in the organic Kingdom" without which no life is possible. Protein is so important. Inspite of so much time since elapsed, no-body yet could question the validity of his statement...it is indeed of grave importance.[26]

Protein nutrition has to be maintained under any circumstances with utmost consideration by giving adequate first class protein. Extensive work has been done in the laboratory where the speaker has the privilege to work, and the summed up results of the investigation are as follows[27] "As we pass from the North West region of the Punjab to the Gangetic plane to the coast of Bengal, there is gradual fall in the stature, body weight, stamina and efficiency of the people. In accordance with this decline in many characteristics it is of utmost significance that there is an accompanying gradual fall in the nutritive value of the dietaries".

In fact, the level of physical efficiency is above all else, a matter of food, no other single factor, race, climate, endemic disease etc., has so profound an influence on physique.

This is not an occasion to discuss a standard of nutrition and nutritional requirements but only on the importance of nutrition in wielding human stock. Even then a few words on some of the difficulties that are encountered in establishing a nutritional level, will perhaps be not out of place. In India this problem seems to be more acute, main cause of which appears to be want of education (percentage of literacy being 16.61)[28] even the best material for nutrition is often rejected. This is milk, proteins of which are amongst the best of all proteins and well able "to leaven the whole lump" of those derived from vegetable food[29]. Beneficial results of incorporting milk for nutrition is not realised by several tribal groups e.g. the Nagas and the Kukis of N.E. India and some of the Chotanagpur tribes like the Hos, the Mundas, the Oraon etc., do not include milk in the dietaries because the N.E. Indian tribes believe that milk is the white blood of cow which is considered to be an object of veneration. The tribal people of Chotanagpur are not accustomed to consume milk, they do not drink milk, not on religious taboo but from mere tradition. Thus the tribal students (Adibasi) of Chotanagpur instead of buying milk with the money granted as stipends by the Government for taking milk, they spend the amount in buying luxury goods particularly when they come to a town from rural homes. Other can not buy milk owing to its high price. Again owing to the ignorance about the beneficial effects of milk there can not be a concerted attempt to increase the yield of milk for people.

Along with protein other proximate principles, namely carbohydrate and fat together with vital biocatalysts comprising vitamins and minerals, the latter being known as inorganic vitamins, are also very much necessary.

The role the biocatalysts play in the body mechanism is even today too difficult for the human intelligence to unravel except making large number of attempts as found in many instance, in ill-defined or ill-understood theories. This is sure and universally admitted that they are indispensable if life is to be sustained and to maintain health which has been defined by the World Health Organisation as a 'state of spiritual, physical and mental well being'. All those referred to above are required for building this health and for its maintenance. Besides, as already shown before, in the absence of one or when one is supplied in inadequate amount a particular substance is formed ignoring the other[30] Whipple et al recorded that protein tends to be diverted for synthesis of haemoglobin rather than formation of plasma protein in subject suffering from hypoproteinemia.

Question of distribution is again of grave concern. It has of late been so serious that the vitality of general public is being gnawed into steadily with the result that the so called middle class people who form the larger bulk of the density of population of the country and strength of the country will die out in no distant time. They cannot obtain the nutritious food because of the prohibiting cost of living, their capacity being too small to procure proper nutrients. Annual income of Indian per capita is only Rs. 252·00 (at current price 1955-56—Preliminary[31]) it is beyond dream to arrange for nutritive dish when the price is so high. As a consequence distribution remains confined to limited wealthy people of the country who overeat and even spoil. It is needed that some sort of device should be formulated out to prevent loss and ensure equitable distribution. Adequate nutrition is thus primarily and basically required for better birth, better growh and better mutual understanding and humanistic approach to a social problem, which is the aim of science of anthropology. Thus hypoproteinamic individual will of course, attain his haemoglobin content well but he will be a wreck in his plasma protein content. Consequently, the oncotic pressure will fall and the individual will allow accumulation of extra water in the extracellular body compartment and tissue spaces. There may be adequate oxygen carriage to the tissue but there are no corresponding user units. Internal constancy will be at stake, digestion, absorption, assimilation will hamper and gradually the individual will slip into the grave.

There is no doubt that it is extremely difficult job to set up scale of nutrition for our country when there are so many taboos, prohibitions, ignorance etc., going rampant in the land of ours. Questions has become still more confronting as the population in the country is on the increase and this over-population and ever increasing population is engaging the attention of many and referred to as grave hindrance to the solution of the problem of inadequate nutrition. Much attention, time and energy are being diverted towards that and ways and means of restriction of population are being thought of with the hope that if population can be restricted that may improve nutrition in the country. Experiments in the laboratory and observation of natural sequences cited below do not lend much support to this idea.[32] Slonaker studied reproductive indices for six generations in rats. He found that diet rich in protein when above 18% of the total calorie intake was unfavourable to reproduction of the species, this diet "increased sterility, retarded the epoch of fertilization in the female and reduced the number of litters and number of youngs in each litter". From a survey made about birth rate and daily consumption of animal protein in gram it will be seen that the highest birth rate is, in Formosa—45·6 with a daily protein consumption of 4·7 gm., next in Malay States— 39·7 with protein consumption of 7·5 gm., in India however birth rate is 33·0 while protein consumption is 8·7 gm. On the other hand Sweden has lowest birth rate (15·0 with 62·6 gm. protein per day, in the United States it is 17·9 with protein 61·4, in Australia the birth rate is 18·0 while protein consumption is 59·9[33] So the issue stands thus : is it the over-population that is causing poverty and dearth of proper nourishment as the Malthusian theory tells us or insufficient nutrition is the cause of over-population? as advocated from historical evolution by well known demographers, Imre Ferenci[34]. Dr. W. R. Aykroyd—sides with the latter. From studies carried out in India, China, Africa, Far East and Latin America under-nutrition has been cited as the cause of over-population. If this idea is upheld, it is all the more incumbent to improve the state of nutrition to meet the situation and the resources now spent for restriction of population may be utilised in this direction.[35] It has to be borne in mind that "Man's science is great but man himself is greater". "শুনহ মানুষ ভাই—সবার উপরে মানুষ সত্য—তাহার উপরে নাই।"

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SECTION OF MEDICAL AND VETERINARY SCIENCES

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PRESIDENTIAL ADDRESS

THE ROLE AND IMPORTANCE OF FUNDAMENTAL SCIENCES IN MEDICAL EDUCATION

Ladies and Gentlemen,

Before I start on my presidential address, allow me to thank the Executive Committee of the Medical and Veterinary Section of the Indian Science Congress, who have been kind enough to elect me as their President this year and given me this unique opportunity to address you. I consider this a great honour and privilege and am proud to deliver my speech before this august audience. In this enlightened assembly I am sure there may be many well experienced medical educationalists, who are stalwarts in this field and who may or may not hold the same views as I have. It is not my endeavour to enter into any controversy. The present position I hold with my Government has given me singular opportunities to study the problems of medical education from a different angle. I am a medical man and a chemist. I feel, therefore, I am in a better position to view the difficulties and the lacunae in our present system of medical education in a dispassionate and unbiased manner. There may be quite a few like me, who take advantage of the knowledge gained in different disciplines and apply them in their daily routine and I expect them to agree with me.

The medical profession all the world over is beset with many problems. This, in a large measure, is due to the rapid advances that are being made in the field of fundamental sciences. Medical science, at the present moment, is dependent almost entirely on fundamental sciences for its progress. The basic knowledge has gone up requiring higher standards and efficiency in the academics of medical science. It is not enough if we continue our age-long standards and methods, in a rapidly progressing world, and to keep pace with it, one has to change or modify them. The standards of medical education, the quality of men that take up this profession, the teaching staff and other related things are some of the burning problems that are engaging the attention of medical educationalists in the advanced countries. Hence, ladies and gentlemen, I have chosen this topic as my presidential address today.

Eminent men in this profession have made a thorough study of these problems and have expressed their candid views on their various aspects. We in India, have got similar problems and in addition some special ones that are peculiar to us. India is a big country consisting of a number of states and the development of each state depends upon several factors—

while some states are very much advanced, there are others still to catch up. It is regrettable that medical education in this country is neither uniform nor always of a high standard. Though the University authorities may protest, I feel strongly that no two Universities have got the same standards, regarding the period of study, scope of subjects etc. for the undergraduate and post graduate courses. Adequately qualified and trained staff, practical facilities, and good clinical material are lacking in some institutions.

What is then the basic knowledge expected of a candidate seeking admission to medical studies? Is it or is it not necessary to teach essentials of the advances made in the fundamental sciences that have a direct bearing on medical science? Very few realise the importance of such a study forming an integral part of pre-clinical course and in some Universities the physical sciences do not find a place in the medical curriculum at all. We in India, by being indifferent to fundamental sciences are not progressing but retrogressing. In a few Universities, some half-hearted stress is laid on the teaching of fundamental sciences in the pre-professional or in the first year of the M.B.B.S. course. This is not enough. Human body is a multipurpose laboratory. The laws that govern its functions are the same as those that govern matter. Life is another attribute of matter. Therefore the place of fundamental sciences in the study of Medical and Veterinary sciences cannot be belittled. Physics and chemistry have progressed by leaps and bounds, almost making man's fantastic dreams come true. We are now living in the age of space conquest and interplanetary travel. New ideas are propounded and fresh discoveries are made, unravelling the mysteries of the universe and the human body. Every average medical man should be aware of the latest developments in medicine, and for a rational and intelligent understanding a sound background of subjects, viz. physics, chemistry, biology and mathematics, is absolutely necessary. Otherwise the study of medicine, reduces itself to a chronology of epochs and events.

Both in the study of medicine at the graduate level and post-graduate research level, one can achieve very little if the fundamental sciences are not learnt. The standard that should be expected of an undergraduate in medicine for a quick and intelligent grasp of the subjects like physiology, biochemistry, pathology, therapeutics etc. is that of a graduate in science. It is paradoxical to note that teaching of physical chemistry, physics and organic chemistry, which was essential to medical students in the last decades, is now found to be less important. Some Universities have unfortunately condensed the course from 5½ years to 4½ years axing the pre-registration course of six months and reducing the pre-clinical study of 2 years to 1½ years and others are rapidly following suit. We are thus building edifices with improper foundations. The ideal of the Universities is not only to produce qualified medical personnel for this vast country but also to retain its academic standards and quality.

The notion that shortening of the medical course would produce more number of medical men is fallacious. The initial advantage is that at the end of the shortened period there would be just an extra batch of medical men in addition to the usual batch of the longer course released to the profession. In subsequent years the numbers of men turned out would depend upon the number of seats available. So the argument that reduction in the period of medical study would provide more number of medical men to the country is a mathematical inaccuracy and a real increase is possible only by increasing the number of intakes. Then what have we gained after all by this reduction? Nothing substantial except that we have narrowed the confines of medical study. In this context I may be permitted to mention that very eminent medical men in western countries advocate a broad based training in subjects like physics, chemistry, biology, genetics etc. as they are not satisfied with their existing standards, which I am afraid are much higher than those obtained in many of our Universities.

The place of mathematics in the study of medicine is not properly appreciated. To understand the various biophysical and biochemical processes, basic mathematics is absolutely necessary. Therefore the popular belief that mathematics does not play any significant role in medical education is wrong. I shall dwell more on this when I discuss the choice of material for this course.

I know that many colleagues of mine will not agree with me, their contention being that it is unnecessary to saddle an average medical practitioner with all details of basic sciences. This sounds apparently reasonable but will not stand a deeper scrutiny. One has to bear in mind that general practitioners deal with a greater cross section of patients and diseases. Very often their intelligent and critical observations have paved the way for newer concepts on the epidemiology, pathogenesis etc. of diseases. The role of general practitioner is not to be underrated.

Moreover, how can Universities, the seats of learning and high academics be expected to manufacture medical men for mere medical relief only? They have more important functions to perform. They must produce qualified teachers, research workers etc. How could they accomplish this if a broad based curriculum is not insisted upon? Otherwise the only solution would be two courses of medical study to cater to the above different needs. The inevitable consequence of such a step would be the creation of a wide gulf between the two sets of medical men, which is unhealthy and should be discountenanced. If the standards in various disciplines are brought down, imagine the ultimate fate of our profession in our country! We will be faced with a crisis. There will be an acute shortage of qualified teachers and research would languish for want of proper guidance. Mere expediency cannot be advanced as an argument to justify the lowering of standards. Therefore it devolves upon us as a soleman duty to prevent any such retrogressive steps in our progressive evolution. I earnestly request the University authorities to fight against this evil of half learning.

The medical studies do not attract the best brains of our country as they are lured away by the administrative services ; as long as the technical men are not given their due status and regard, the profession has to rest satisfied with whatever material they get. I cannot but point out at this juncture that often the advice of technical men is not sought and even if sought is not acted upon. He is often ignored by the administrative hierarchy. In our country, the status and even the brilliance of an individual are evaluated in terms of his pay and allowances. It is an admitted fact that medical profession is poorly paid and how can one expect any enthusiam in such a set up? Unless and until effective measures are taken to remedy this anomaly, a bright future for this profession cannot be envisaged.

Let us consider now the standards by which selection is made from the material that is available. The performance at the pre-university or at the intermediate course as the case may be is the criterion or yardstick for assessing the merits of a candidate for admission to the course. Some of the colleges are excluding graduates from entering the portals of this profession. It is strange that men with more maturity of wisdom, are denied admission to the faculty, which insists upon amongst other things, maturity of age, thought and vision. It is quite likely that many may be average in their attainments at their pre-university life, but blossom later on into brilliant men in their college career. So, there shall be provision in each college to allot at least 10% of the admissions to brilliant graduates in science every year. Later on, the Universities and Colleges can draw on these men to fill up suitable posts in the teaching and research lines.

Another drawback of recent introduction is the denial of admission to students of mathematics to the medical course. This is definitely retrograde and harmful. I do not know how this virus of prejudice against mathematics has got hold of the medical educationalists. Unless these barriers and narrow-minded prejudices are removed and admission thrown open to graduates and mathematics students, it will not be possible to get the best material for this profession.

The non-clinical branches of medicine comprising of bio-chemistry, physiology, pharmacology, bacteriology, chemical pathology, toxicology etc. require a very high degree of proficiency in natural sciences—physics and chemistry and also in natural history—botany and zoology. The modern concepts of these branches are mostly protein and enzyme chemistry. The study of pharmacology and toxicology is one of advanced organic chemistry. How can we aspire for experts in these subjects if brilliant science graduates are denied admission to medical course? I may be permitted to quote in this connection, Dr. W. Melville Arnott, William Withering Professor of Medicine in the University of Birmingham, in the Matheson Shaw Lecture delivered before the Royal College of Physicians of Edinburgh in November 1958 "Though medicine in general requires people of considerably above average ability, the greatest good of mankind is served by securing for science and technology the very best. Within the field of medicine itself the same cold logic shows that the greatest good is likely to result from having the best brains in such divisions of medical science as biochemistry, physiology, immunology, pharmacology and clinical science rather than in purely clinical work."

Already there is a paucity of such qualified medical men for these special branches, necessitating the recruitment of non-medical specialists. Even the very best of them is an outsider and he cannot effectively assist and direct the clinicians. The important and vital link is wanting. According to Dr. W. Melville Arnot "this is not in itself a disadvantage as the principal quality which should be instilled into the student is scientific discipline. Nevertheless a proportion of the preclinical teachers should be medical men, because it is desirable to introduce some vocational bias into the teaching of physiology, while it is rare to be an anatomist without being a medican man. The root of the matter lies in the discrepancy in remuneration between clinician and non-clinician. This itself is the interface between the academic better off academic clinicians and other members of the University of equivalent status."

The method of selection to the professional course is made on an initial grading according to the previous academic record and the final ranking is done by interviewing the candidates. There is a tendency to attach too much importance to interview part. Such a system of selection is not free from criticism as it is difficult to assess the merits of a candidate in so short a time. Statistical analysis and follow up of the selection based on these criteria for a number of years have been compiled and the inferences are that past academic record is a most useful criterium for indicating future academic success and interviews have a low predictive value. Distinguished scholastic career indicates a capacity for hard work or an intelligence above the average, qualities which are prerequisites for success in any walk of life.

Research in medical sciences has not made much headway in our country. Most of our brilliant men choose the more remunerative clinical line in preference to research and non-clinical branches and the people, who take up to research do it in a haphazard and half-hearted way waiting for the earliest opportunity to leave it in favour of more attractive jobs. Further research workers cannot be labelled from the very beginning. It is largely by trial and error that people with research capacities can be chosen which means a good number of persons must be watched over a minimum optimum period (usually about 3 years) and their potentialities assessed. There is bound to be an unavoidable wastage in such a process of selection, which has to be ignored in the interest of progress.

Research is exacting and needs a very broad based education in fundamental sciences. I have already dwelt in sufficient detail on this but I feel it is not superfluous, were I to reiterate its importance particularly in the field of research. Unless we have a sound foundation in basic sciences, a stable superstructure cannot be constructed. In short medical research needs brilliant, hard working men with research bent of mind and a sound knowledge in fundamental sciences.

Modern research centres mostly round laboratories. Unfortunately today adequately qualified men of experience are not available to man these laboratories. Why? Research is a hard task master and needs patience, perseverance and full time devotion. Research is least remunerative and often goes unrewarded. So if research is to be encouraged, firstly men with proper background must be selected without any prejudice, paid handsomely and be allowed full freedom in their work. Many of our directors of research are shackled with heavy correspondence, often irrelevant and unnecessary, just to satisfy the vaious administrative machineries. Not only does he thus waste hours of his precious time, which otherwise could have been more profitably utilized but also he loses his concentration and trends of thought by such disturbances. Steps must be taken to remedy these defects and make him a master of his time and work.

There is another vital problem that confronts us all to-day consequential to the rapid and vast advances made in all branches of science resulting in a wide range of narrow specialities and that is "isolationism."

In this session though all the disciplines and faculties are presented, you will find without my specific observations and remarks, the poor representation of our faculties. This is because, the medical faculty has a number of minor disciplines and each has its own All India Association. They conduct their sessions at different times of the year and at different places. Isolationism practised by members of this faculty is neither surprising nor unique. Even in advanced countries, where medical science has almost gained the place of an exact science, it is felt that there is lack of co-operation and exchange of ideas, with other faculties. This has led to an unusual complacency and more and more of blind empiricism. Of course it is not possible to gather them all under the aegis of the Science Congress but a fair representation from individual disciplines must be there.

I am sorry I have been concentrating all the while on medical studies and medical profession. This is pardonable being a medical man myself. Veterinary science, though practised in our country from ancient times, is still a neglected field. This faculty is a sister of medical faculty and so whatever I have said of medical is also applicable to this.

In an agricultural country like ours, animal wealth is a measure of our prosperity. It is true our cattle wealth is enormous but the returns are not at all commensurate with the number. According to Mr. Indubhusan Chatterjee, Ex-Assistant Agricultural Commissioner with the Government of India "the production of cow and buffalo milk is worth Rs. 987 crores, the huge maintenance cost of large number of unthrifty animals is involving the country into an annual lost of Rs. 774 crores equivalent to 6 to 7 times of what we are annually spending in importing food grains."

The maintenance of quality breed is not possible unless and until we have a number of adequately staffed veterinary hospitals and research institutions to effectively advise on matters of nutrition, health and improvement of livestock. If we feel that progress in medical research leaves much to be desired, the position regarding veterinary science is even worse. Moreover, the profession is not as attractive as medical. Hence very few volunteer to take up this profession. People must realise that animals play a vital role in the economy of man's life. They should rise above their prejudices and patronise the veterinary faculty in greater numbers.

I feel strongly that persons engaged in medical and veterinary research should attend the Science Coggress sessions and mix with fellow scientists, learn the modern advances, methodology and techniques in other fields. It must not be forgotten that medicine is an applied science. I regret that opportunities like these are not exploited by our profession. Instead the profession is dismembered into a number of specialities and each one rests supremely contended and complacent by holding its own meetings and discussions. This drift, though justifiable to a certain degree is neither congenial nor desirable in the larger interests of our faculties. If such a state of affairs is allowed to continue, stagnation would be the ultimate inevitable result. Therefore I appeal to all academicians and research workers in these faculties to take active part in such general sessions, contribute their mite, assimilate fresh ideas and utilize them.

I hope I have sufficiently stressed my views and have succeeded in bringing home to you the importance and role of fundamental sciences in the study of medical and veterinary sciences. I want you to remember that medical science is a technology in fact. Most of the modern advances in medicine are directly related to advances in fundamental sciences. To mention a few, the study of mineral metabolism by tracer techniques, the treatment of malignant diseases by radio-active isotopes, the various physical methods like paper chromatography, electrophoresis, electro-cardiogram, electro encephalogram, etc. in the study and diagnosis of diseases and assessment of the efficiency of treatment. I am sure you will all agree with me, on the fact that the medical science depends on fundamental sciences for its progress. It is the nucleus of our modern medicine. I appeal fervently to the medical educationalists of our country to be alive to this fact and to give the due importance it deserves in the medical curriculum.

Ladies and gentlemen, I thank you for the patient hearing you have accorded to me.—Jai Hind.

SECTION OF AGRICULTURAL SCIENCES

President :—B. N. SINGH, Ph.D. (Dublin), Ph.D., D.Sc. (London)

PRESIDENTIAL ADDRESS

INTER-RELATIONSHIP BETWEEN MICROPREDATORS AND BACTERIA IN SOIL

I should like to thank at the outset the members of the Agricultural Sciences sectional committee for unanimously electing me President for this session.

It is well known that a fertile field soil contains teeming millions of a complex population of microscopic life consisting of bacteria, fungi, actinomyces, algae, protozoa and so on. This population is not only large but also very varied. They are of great importance to crops since some of them are the agents that prepare the soluble food materials available to the crops. Different types of organisms differ very much in their usefulness in this respect, so that not only the quantity but also the quality of the microbial population must have an important influence on crop growth. Before we try to answer the question generally asked by a layman,—" How can the study of Soil Microbiology produce results of practical importance to Agriculture?"—it is important to answer two primary questions: (1) What are the common species of micro-organisms present in different types of soils? and (2) Why are they common? Anwers to these questions may provide means for encouraging the predominance of the more useful species and the suppression of the harmful types, and so improve the soil's fertility.

The effect that micro-organisms and their metabolic products have on one another are very varied and complex ; it is, moreover, becoming increasingly evident that they are of great practical intrest to mankind ; this is true in many industrial processes, in the soil, in animal tissues, and hence in the treatment of disease. The interactions may be due to straight forward competition between organisms with the same needs occupying the same habitat, or to the effect that the metabolic product of one may have upon the existence of the other or to the fact that one group of organisms prey upon the other. I shall deal in this address mainly with the last type of interaction.

The pioneering investigations of this kind in Soil Microbiology were started in 1919 by Ward Cutler and his colleagues, under the inspiring leadership of Sir John Russell, at Rothamsted Experimental Station, England. Cutler *et al* (1922) counted every day, without a break, for three hundred and sixty-five days protozoa and bacteria numbers in a plot of arable ground. Rapid fluctuations in the numbers of active protozoa and bacteria were found and it did not appear that temperature, moisture content or air supply were determining causes. The rise and fall in numbers of active amoebae were inversely related to that of bacterial numbers. This indicated that amoebae, which feed on bacteria, were probably the cause of the fluctuations in the bacterial numbers. Experiments done later by Cutler (1923) showed that amoebae did keep down the numbers of bacteria in sterilized soil. Why amoebae fluctuated was not clear?

More recently, it has been shown that microscopic predacious fungi parasitising and preying on nematodes, amoebae and testaceous rhizopods are commonly present in soil (see Duddington, 1955 ; Peach, 1955). Weber *et al* (1952) and Zwillenberg (1953) discovered an amoeboid proteomyxean organism that feeds on potato root eelworm and other nematodes. These interactions of an organism preying upon the other has an important bearing on the biological control of certain plant diseases and on the microbial ecology in soil. The dominance of certain groups and the prevalence of organisms having specific effects, whether beneficial or harmful, are of great practical importance to Agriculture. In this article I shall confine my attention mainly to the work relating to the complex inter-relationship that exists between certain micro-predators and bacteria and the probable effect of this interaction on their ecology in soil.

Interest in soil protozoa and bacteria relationship dates back to the work of Russell and Hutchinson (1909) on partial sterilization of soil. They drew attention to the fact that protozoa are primarily devourers of bacteria and attempted to account for the development of ‘ soil sickness ’ by supposing this to be due to an excessive number of active protozoa which diminish the bacterial population and for the remedial effect of partial sterilization by suppression of these protozoa by sterilizing agents. The theory of Russell and Hutchinson (1909) has, however, never been fully accepted. Laboratory experiments with pure cultures of bacteria with and without the additions of protozoa have shown that the latter do not always depress the biochemical activity of bacteria, but may in fact stimulate it under certain conditions (Nasir, 1923 ; Cutler and Bal, 1926 ; Cutler and Crump, 1929 ; Harvey and Greaves, 1941 ; Meiklejohn, 1930 ; 1932). Earlier investigations at Rothamsted Experimental Station and elsewhere had shown that soil contained large numbers of flagellates and amoebae population in an active and trophic condition. These findings, the theory of Russell and Hutchinson (1909) and the discovery of Cutler *et al* (1922), as outlined earlier in this address, raised the question whether amoebae and holozoic flagellates have the ability to feed differentially on bacterial species. Some work suggested selective feeding of amoebae on bacteria (see Singh, 1941*a* for references), and it became important to find out whether amoebae could select their food from a mixture of bacterial species, as such are available in field soil.

CAN AMOEBAE SELECT THEIR FOOD AMONG MIXED BACTERIAL POPULATION?

In order to study this problem suitable methods were devised (Singh, 1941a). Amoebae migrate in all directions on the plate when they are placed either in the centre of bacterial circles or stars. This difficulty was overcome as follows : pieces of thin glass tubes were arranged inside a Petri-dish in as many radii as desired and non-nutrient agar (1.5—2.0% agar in 0.5%NaCl ; pH 6.8—7.0) was poured in between the glass tubes. Young cultures of different bacteria of the same age, growing usually on nutrient agar slopes, were spread on the non-nutrient agar surface as streaks along the radii, each redius consisted of a different kind of bacteria.

Roughly the same quantity of each bacteria was used. In the centre of the bacterial stars large numbers of amoebae were inoculated and allowed to move in all directions. After reaching a suitable food supply, the amoebae ate, multiplied and moved along the bacterial streaks. When they reached the non-edible food supply, they either encysted or died without apparently destroying these bacteria. The preference for one type of food as opposed to the other was judged by the amount of bacteria destroyed in a given time. In another series of experiments two streaks, consisting of two different kinds of bacteria, were made touching each other and the amoebae were inoculated in the centre of these streaks. They were found to eat the edible types leaving the non-edible ones alone. In the third series of experiments small patches of a number of bacterial species were made on the agar surface in between the glass tubes and the amoebae were inoculated in the centre. The amoebae although moving in masses in between the edible and non-edible food supplies, ate only the former and left the latter untouched. They either encysted or died when they reached unfavourable food or they moved on in search of favourable food and when they found it, they consumed the bacteria and multiplied.

By the above methods, Singh tested in 1941 (a) two species of unidentified amoebae on five strains of *Aerobacter* and twelve species of soil bacteria, and subsequently in 1942 (a) on sixteen strains of *Rhizobium*, twelve other species of soil bacteria and twelve species of plant pathogenic bacteria. In 1945 a further sixty-three species of soil bacteria and thirty-nine ' miscellaneous ' bacteria were tested. The species of bacteria used in these experiments differed widely in their morphological and biochemical characters and about half of them were eaten by the amoebae. The two species of amoebae resemble closely in their feeding reactions, differing in respect of only seven bacteria. These are only partly eaten by the large amoeba, while they are eaten slowly but completely by the small one. Bacteria could be classified on the basis of their edibility into (1) species readily but completely eaten, (2) those that were slowly but completely consumed, (3) those that were partly consumed and (4) an entirely non-edible group. No correlation between Gram-staining, motility, presence of proteolytic ferment, slime production etc. in bacteria and their edibility to amoebae could be found. Nearly all the red, green or blue pigmented bacteria, other than yellow or orange, were inedible. Thus the production of certain pigments by bacteria give them protection against amoebal attack. Some bacterial species were found to produce secretions toxic to amoebae and in some cases the pigment itself was found to be toxic (Singh, 1942 b ; 1943 ; 1945).

This work suggests that amoebae may be affected by the quality of bacterial food or conversely their numbers may be affected by the proportion of edible and inedible bacteria present in soil. Not only amoebae tend to form cysts in the presence of unsuitable bacteria but the presence of certain bacteria are necessary for excystment of amoebae and other protozoa (see Beers, 1946 ; Crump, 1950 ; Singh 1941*b* for references). Singh *et al* (1956) demonstrated, at Central Drug Research Institute, that a strain of *Aerobacter sp.* produced in actively proliferating culture an amoebae excystment factor, which was capable of diffusing easily through collodion membrane ; the factor was thermolabile and its activity was somewhat dependant on the pH value of the medium. More recently, Singh *et al* (1958) discovered that aqueous extracts of *Aerobacter sp.* and *Escherichia coli* caused excystment of viable sterile amoeba cysts. The factors which caused excystment were thermostable. By paper partition chromatography they showed that part of the excystment inducing activity of the aqueous extract of *Aerobacter sp.* was due to the presence of amino acids, some of which were identified. Certain chemically pure amino acids and nucleotides were also found to cause excystment.

Thus a highly specific inter-relationship between soil amoebae and bacteria is found under laboratory conditions. In order to study whether amoebae can select their food in soil the following experiment was performed (Singh, 1941*a*). An edible yellow and an inedible red bacteria were inoculated in sterilized soil together, with or without the addition of amoebae. These bacteria were also inoculated singly in soil without the amoebae. Counts of bacteria by plating technique at different intervals showed that the yellow bacteria were destroyed by the amoebae ; their number was at a much lower level in the soil containing amoebae than in the control soils. In the absence of amoebae, the bacterial numbers fluctuated greatly. The red inedible bacteria were not much affected and after a month regained the numbers found in the control soils. When the number of edible bacteria became very low, the count of amoebae showed that they were in cystic condition. Thus it seemed that amoebae were unable to eat the red bacteria, although they were present in large numbers. The result in sterilized soil was in complete agreement with that obtained in pure culture experiments.

CAN THE QUALITY OF BACTERIA AFFECT THE NUMBER AND QUALITY OF AMOEBAE POPULATION IN FIELD SOIL ?

In order to throw light on the first question a greatly improved dilution culture method giving valid estimates of amoebae in soil was devised (Singh, 1946*a*, *c* ; 1955) and to answer the second, taxonomy of small free-living and soil amoebae was developed (Singh, 1950 ; 1951 ; 1952 ; 1953*a*).

Direct microscopic examination of soil has failed to give reliable picture of amoebae population because their numbers are too small to be counted in stained films and it is difficult to separate them from the soil mass to which they are firmly held by soil particles (Cutler, 1919). Cutler (1920) published the first dilution culture method of counting active and cystic amoebae and other protozoa that has been statistically approved. This method is limited in accuracy due to the following reasons : (*a*) the difficulty of obtaining sufficient replication, where a wide range of soil dilutions (usually 15), is necessary, since the numbers of amoebae may vary from a few thousands to several hundred thousands (Cutler *et al* 1922) ; (*b*) by examining the whole surface of nutrient agar plate, thickly covered with all sorts of micro-organisms, it is easy to miss the presence of small numbers of amoebae ; (*c*) a serious error—more disturbing because its magnitude is difficult to assess—is the source of bacterial food supply, this is a random collection of such bacteria, derived from soil suspension, as may happen to grow on nutrient agar plates, and an amoeba in a given sample may fail to grow or may be killed if it lies on a portion of nutrient agar amongst inedible or toxic bacteria or fungi.

These difficulties were overcome in the method devised by Singh (1946*a*, *c*). Selective feeding tests showed that strains of *Aerobacter* and certain other bacteria were readily and completely eaten by a range of species of amoebae and other holozoic soil protozoa (Singh, 1941*a*, *b* ; 1942 ; 1945 ; 1946*a* ; 1952). This enabled the use of a pure culture of an edible bacteria, placed in a Petri-dish on the surface of washed non-nutrient agar or silica jelly, on which toxic or inedible bacteria from soil dilution would make little or no growth. The replicate sample at each dilution was increased to eight, instead of two as used by Cutler *et al* (1922), by imbedding in agar or silica jelly eight glass rings in a Petri-dish. The entire surface in each glass ring can be readily and rapidly explored. Thus the error involved in sampling an entire plate surface is obviated. Extensive tests (Singh, 1946*a* ; 1949) have shown that this method gives reliable estimates of amoebae, ciliates and holozoic flagellates in soil. The application of this method revealed that Rothamsted field soils contained more amoebae than flagellates (author's unpublished data) whereas Cutler *et al* (1922), using nutrient agar, found that the number of flagellates exceeded that of amoebae. Thus amoebae are numerically the most important group of soil of protozoa that feed differentially on bacteria.

By the use of this method a survey of the active and cystic amoebae population in plots on Barnfield and Broadbalk (Singh, 1949) at Rothamsted and in partially sterilized field plots (Singh and Crump, 1953) at Ampthill, Bedfordshire, England, were made. It is generally believed that the presence of plenty of organic matter in soil will favour an extensive development of bacteria, which in their turn will be accompanied by an abundant development of protozoa and other micro-predators. To test the validity of this belief about amoebae, counts of these organisms were made on nine occasions from Barnfield and on six occasions from Broadbalk plots. The three plots selected from Barnfield (permanent mangolds) were : 8·0, untreated ; plot 1·0, receiving 14 tons of dung/acre/year ; plot 4A receiving a dressing of complete minerals (3½ cwt. of superphosphate, 500 lb. of potassium sulphate, 200 lb. of sodium chloride and 200 lb. of magnesium sulphate), and 412 lb. of ammonium sulphate/acre/year. These plots had been treated in this way continuously since 1876. Three similar plots were selected from Broadbalk (permanent wheat) ; plot 3, untreated; plot 2 receiving 14 tons of dung/acre/year ; plot 7, receiving complete minerals (3½ cwt. of superphosphate, 2 cwt. potassium sulphate, 1 cwt. sodium sulphate and 1 cwt. of magnesium sulphate), and 4 cwt. of ammonium sulphate/acre/year. Plot 2 had remained unmanured since 1839. Wheat was being grown in each of the plots since 1852 and the fertilizer treatments were the same each year. Marked fluctuations in the numbers of ameoebae were found in all the soils. In both the field, the total (active + cystic) and active amoebae were much lower in the untreated plots but did not differ appreciably as between the plots treated with farmyard manure or complete minerals + ammonium sulphate. The percentage of organic carbon was roughly the same in untreated and artificial fertilizer treated plots, while it was much higher in farmyard manured plots. The bacterial numbers from the same samples both by direct and plate counts (Skinner *et al*, 1952) from the Broadbalk samples were much higher in the farmyard manured plot than in the other two plots, whose bacterial numbers were similar to each other. Thus it seems that the quality of bacterial food must account for the different relative effects of manurial treatment on amoebae population.

It is of interest that the yields of mangolds and wheat in untreated plots were about one-third those of farmyard manure or complete minerals + ammonium sulphate, as are also the numbers of amoebae in these plots. No marked differences were found in the yields of the plots treated with farmyard manure or with artificial fertilizers. Thus the crop yields and the population of amoebae were correlated in both the fields. It may be emphasized that the treatment of soils with artificial fertilizers for a very long time had no detrimental effect on amoebae, but had in fact much incrased their numbers in comparison with those in the untreated plots.

The earlier investigations on amoebae in partially sterilized soils were carried out under laboratory conditions. The programme of field trials carried out at Ampthill on Sitka spruce nursery plots, some of which were treated with steam and formalin, provided an opportunity to investigate the action of these agents on the numbers of active and cystic amoebae and bacteria under field conditions (Singh and Crump, 1953), while modern technique for estimating numbers of amoebae (Singh, 1946*a, c*) has greatly improved the validity of the results now obtainable. Small plots were steamed for about 20 min., using four grids at a time, each grid having five pipes, 4 ft. long and 9 in. apart buried at a depth of about 9 in. A solution of 10% commercial formalin in water at the rate of one gallon/sq. yd. was added to the formalin treated plots. No counts of amoebae from duplicate field soil samples were made because the differences between a number of duplicate field soil samples in earlier work (Singh, 1946*a* ; 1949) were in no case found to be significant. In the first count taken between 7—14 days of the treatment with steam and formalin, showed that all the active amoebae were killed leaving the cystic forms apparently undamaged because their numbers did not differ significantly from the cystic numbers found in the untreated plot. Immediate fall in bacterial numbers, as estimated by plate counts, was also found. After this, in the steamed plot the number of both amoebae and the bacteria rose very much higher than in the untreated plot. In the formalin treated soil the number of bacteria rose well above those in unteated soil but the numbers of active and cystic amoebae were much lower on the whole as compared with the control soil. When formalin was applied once again to the same plot after a year, the amoebae population was further decreased. This effect of formalin treatment on the numbers of amoebae was found to persist over a period of six months. Crump (unpublished data) found that bacterial flora in formalin and steam treated soils were to some extent qualitatively different, and that this difference persisted over a long period. This suggests the importance of the quality of bacterial flora for the growth of amoebae in field soils, a result to be expected from the earlier laboratory experiments on differential feeding carried out by the author.

A difficulty constantly met with in studying soil amoebae is because of their correct identification. The taxonomy of small amoebae was based by previous workers on characters too uncertain to be of practical value. The types of nuclear division are one of the stable characters, but the difficulty of getting the various stages of division limited the use of this character. Due to the work on differential feeding, it became possible to discover a simple method by which all the stages of nuclear division could easily be obtained (Singh, 1950). A suitable edible bacterium is spread on a thin film of non-nutrient agar on a glass slide and amoebae are inoculated in the centre of the film. As amoebae wander through the agar on to the glass surface, the agar film is removed after vigorous growth and reproduction of amoebae. Large numbers of amoebae are left adhering to glass slide and on a single slide, confined in a small area, all stages of division can be seen. With this method and Feulgen-reaction the nuclear division of a number of amoebae was studied. This resulted in a new system of classifying amoebae based on their nuclear division and possible phylogenetic relationships (Singh, 1951 ; 1952 ; 1953*a*).

No detailed study of the dominant species of amoebae in various types of soils has been made by the use of the new system of classifying amoebae. *Naegleria gruberi* Schardinger was recorded to be a very common soil form by Sandon (1927). Cutler *et al* (1922), in their daily count of bacterial and protozoal population of Barnfield farmyard manured soil, found it to be the dominant species. The writer was unable to isolate this amoeba from the Rothamsted soils during a period of over ten years. *Hartmannella rhysodes* Singh was found from 1945 to 1948 in large numbers in Barnfield and Broadbalk soils receiving farmyard manure, complete minerals + sulphate of ammonia and no manure. In the farmyard manure and artificial fertilizer treated plots, it was found in the highest dilution used, i.e. at 1/1,638,400 on several occasion and it was by far the most common soil form at Rothamsted. *H. leptocnemus* Singh, *H. agricola* Goodey n. comb., *Schizopyrenus russelli* Singh, and *S. erythenusa* Singh also appeared to be common while *S. atopus* Singh, and *H. glebae* Dobell were rarely found in the Rothamsted soils (Singh, 1952).

COMMON OCCURRENCE IN SOIL OF OTHER MICROPEDATORS THAT FEED DIFFERENTIALLY ON BACTERIA

The use of plain (non-nutrient) agar or silica jelly with a suitable pure culture of bacteria as food supply, for counting amoebae, resulted in revealing the common occurrence of giant multinucleate Rhizopod of the genus *Leptomyxa* Goodey (Singh, 1948*a, b*), *Acrasieae* (Singh, 1946*b* ; 1947*b, c*) and higher Myxobacteria (Singh, 1947*a* ; Singh *et al* 1958) in soil which feed differentially on certain bacteria. They thus constitute a factor of importance affecting soil microflora.

GIANT RHIZOPOD

Goodey (1915) first isolated *Leptomyxa reticulata* Goodey from a few soils receiving large quantities of farmyard manure. A single large multinucleate organism, which may attain a diameter of 3 mm., looks like a small plasmodium of an endosporous Myxomycete, but without the regular streaming movement found in the latter. Sandon (1927) could not find this organism in any one of the soils that he examined from various parts of the world. This was because of the use of hay infusion and nutrient agar which encourage the development of inedible and toxic micro-organisms. Mc Lennan (1930) found *L.reticulata* associated with hop disease in Tasmania. Singh (1948*a*) recorded it from all the twenty-six arable and twelve out of thirty-three grassland soil samples obtained from ten counties in Great Britain. All the nine soil samples of the classical plots of Barnfield and Broadbalk at Rothamsted, treated with either farmyard manure or artificial fertilizers or untreated, contained *L.reticulata*. A few counts that were made by the method of counting amoebae (Singh, 1946*a*) from Barnfield farmyard manured soil, revealed its presence upto the soil dilution of 1/1,000. Since the volume of an individual is about 1,000 times that of a typical soil amoeba, the numbers of bacteria needed to maintain their numbers in soil are likely to be considerable. No correlation between pH of the soils and the distribution of *L.reticulata* was found in soils ranging from pH 4.3 to 7.8. Similarly in the presence of a suitable bacterial food supply, pH of the non-nutrient agar between 4.2—8.7 has no effect on the growth, multiplication and cyst formation of this organism.

Edibility of ninty-two strains of very varied bacteria was tested on *L.reticulata* (Singh, 1948*a*). The bacteria fell into three groups, some of them were completely eaten, others were partly eaten, after which *L.reticulata* died or encysted, and the remaining bacteria were inedible. 44.5% of the bacterial strains were completely eaten. Red, violet and green bacteria were not suitable food and no correlation between edibility and Gram-staining could be found. This resembles the feeding reactions observed in the case of amoebae (Singh, 1945). In the presence of certain completely or partly edible bacteria, *L.reticulata* produced multinucleate cysts in clusters resembling the sclerotium of an endosporous Myxomycete (Singh, 1948*a,b*). Among the forty strains of completely edible bacteria, which were tested, only fifteen led to the production of cysts in large numbers, the remaining strains gave rise to only few or no cysts. A strain of *L.reticulata* lost its property of forming cysts after being sub-cultured for a year on *Aerobacter sp.* which is readily and completely consumed.

The observations of Mc Lennan (1930) on the occurrence of *L.reticulata* in hop tissues suggests that parasitic Plasmodiophorales may have been evolved from free-living forms like the former.

ACRASIEAE

A second group of micro-organisms, whose presence as regular soil inhabitants was revealed (Singh, 1946b ; 1947b,c), are the amoeboid protists included in Acrasieae. They occupy a position near the divergence of plant and animal kingdoms. The vegetative stage consists of myxamoebae which feed and reproduce like true amoebae, but under suitable conditions of culture they produce fruiting bodies of definite and consistent form. The Acrasieae have been considered by botanists as plants and by protozoologists as protozoa.

The genera *Dictyostelium* and *Polysphondilium* were created by Brefeld in 1869 and 1884 respectively and species belonging to these genera have since been described. The occurrence of Acrasieae in Polish and American soils was recorded by Krzemieniewski (1927) and by Raper and Thom (1932). Singh (1947*a*) examined sixty-seven samples of arable and grassland soils from ten counties of Great Britain. *Dictyostelium spp.* were present in thirty-three of thirty-eight arable and in three out of twenty-nine grassland soils. In addition, all the differently treated and untreated soils of Barnfield and Broadbalk fields at Rothamsted contained *Dictyostelium spp.* No correlation between the pH of the soil and the distribution of *Dictyostelium spp.* was found in soils ranging from pH 4.3 to 7.8. The pH of the non-nutrient agar between 4.1 and 8.9 did not have any effect on the growth of myxamoebae and the formation of fruiting bodies when the myxamoebae were supplied with a suitable edible bacteria. The method of counting amoebae (Singh, 1946a) revealed the presence of *Dictyostelium spp.* in Rothamsted soils at several higher dilutions. The formation of fruiting bodies, however, was so erratic that it was not possible to count satisfactorily the numbers of myxamoebae or spores.

Ninty-three strains of every varied bacteria were tested on *D.mucoroides* Brefeld and *D.gigenteum* Singh. Some of the bacterial strains were completely consumed, others were only partly eaten and the retst were inedible by myxamoebae even when they were the only food supply. The two species had a marked preference for non-pigmented strains. Red, violet and green bacteria were the least suitable, although, unlike soil amoebae, these organisms can feed on some such strains. Gram-negative strains were somewhat more frequently eaten than the Gram-positive, as was also observed by Raper (1937). Several strains of bacteria that were either completely or partly eaten, induced the production of fruiting bodies that were abnormal in character. Some of the coloured bacteria occasionally led to the production of a few fruiting bodies red or yellow in colour. These findings have obviously an important bearing on the creation of species of Acrasieae (see Singh, 1947*b*).

In soil economy, the importance of Acrasieae depends first, on whether the myxamoebae can lead an active and trophic existence in soil and, secondly, on whether they are present in field soils in sufficient numbers to diminish certain types of bacterial population. Myxamoebae of *D.mucoroides* and *D.gigenteum* greatly reduced the bacterial numbers in sterilized soil ; this effect was more marked with the former species (Singh, 1947*c*). The moisture content of the soil had a marked effect on the migration of myxamoebae and the formation of fruiting bodies in the soil. No fruiting bodies were formed at 8, 10 and 15% moisture contents. At 19, 25 and 33%, fruiting bodies appeared but the production was quicker at 33% than at 19 or 25%. The spread of myxamoebae and the formation of fruiting bodies were unchanged when the moisture content was increased from 33 to 40%. The migration of myxamoebae through soil was approximately 1 in./24 hr. at suitable moisture contents as was found by Thornton and Gangulee (1926) for the spread of *Rhizobium spp.* in sterilized soil. The quality of the bacterial flora added to sterilized soil affected the development of *Dictyostelium spp.* and this was reflected in the number of fruiting bodies produced.

Kubiena and his colleagues (see Kubiena, 1938) in their extensive studies in micropedology by direct observation of various soils have given excellent photographs of the fruiting bodies of *Dictyostelium spp.*, although they identified them as fungi. The identification of these organisms as Acrasieae is supported by the fact that they could not grow them on media suitable for fungi even after repeated trials. *D.mucoroides* was also found by Singh (1947*c*) to pass its life cycle in fresh unsterilized soil. The direct evidence that the amoebae of Acrasieae lead an active life in soil, whether sterilized or not, lends support to the indirect evidence from dilution counts that true amoebae are also active inhabitants, since the two types of amoebae are identical in their feeding habits and the general mode of life.

HIGHER MYXOBACTERIA

Myxobacteria were recognised by Thaxter (1892) as an independent group. Although over fifty species have been described, we know very little about these interesting organisms apart from their morphology, and some are known only by the description of their fruiting bodies. In the active stage they consist of thin rods which collect to form swarm and give rise to fruiting bodies of different patterns. Inside these fruiting bodies the rods turn into microcysts. A microcyst germinates under favourable condition and gives rise to an active rod capable of sliding motion.

The earlier workers considered Myxobacteria to be dung organisms, because they isolated them from the dung of various animals that had laid on the ground for some time. These organisms have been shown to be common by Krzemieniewskis (1926) in Polish, Beebe (1941) in

American, Singh (1947*a*) and Noren (1951) in British, Noren (1950) in Swedish and Singh *et al* (1958) in Indian soils. Their occurrence in all the classical plots of Barnfield and Broadbalk at Rothamsted shows that they are true soil inhabitants and not dung organisms as was previously supposed. Counts from Barnfield farmyard manured soil by the dilution culture method of counting soil amoebae (Singh, 1946*a*) showed that their numbers ranged from 2,000 to 76,000 per gram of soil (Singh, 1947*a*).

The favourable influence of bacteria and fungi on the growth of Myxobacteria was stressed by the earlier workers. The lysis of both the dead and the living bacteria by Myxobacteria has been studied by several workers (see Florey *et al,* 1949 ; Noren, 1955 ; Singh, 1947*a ;* Singh *et al,* 1958 for references). Singh (1947*a*) showed that some species of Myxococcaceae undoubtedly cause lysis living bacteria upon solid agar media. These predators are selective in the bacterial species which they attack. Some bacteria were completely lysed, others showed very slight partial lysis and the rest were not lysed. Pigmented strains seemed to be more resistant than the non-pigmented and more Gram-negative than Gram-positive bacteria were attacked. Mathew and Dudani (1955) and Singh *et al* (1958) found that *Myxococcus virescens, M. fulvus* and *Polyangeum fuscum* were able to lyse dysentery, cholera and typhoid groups of organisms to varying degrees on solid media.

Singh (1947*a*) developed for the first time a plating technique by which these organisms could be obtained in pure cultures free from living bacteria and other micro-organisms, and was able to grow *M. virescens* and *M. fulvus* in mass liquid culture on only dead bacteria. Some of the purified strains were later grown by Oxford and Singh (1946) and Oxford (1947) in a simple cell-free casein hydrolysate liquid medium. A stain of *M. virescens* in this medium produced two substances, an exocellular lytic (proteolytic) enzyme and an antibiotic. This work of Oxford and Singh has been confirmed and extended to other strains of Myxobacteria by Noren (1955). A further study of the production and activity of these substances may throw light on the mechanism of antibiotic activity in general.

NUMBER OF BACTERIAL SPECIES IN SOIL LIABLE TO ATTACK BY MICROPREDATORS

The selective attack on different bacterial species by micropredators adds to their interest from the point of view of soil ecology. Singh tested eighty-seven strains of very varied bacteria, comprising common and rare strains from soil, pigmented and non-pigmented ' miscellaneous ' strains, plant pathogenic bacteria and strains of *Rhizobium spp.* on eight micropredators belonging to four different groups commonly found in soil. The micropredators were a small and a large unidentified soil amoeba, a giant amoeboid organism (*Leptomyxa reticulata* Goodey), two species of Acrasieae (*Dictyostelium mucoroides* Brefeld and *D. gigenteum* Singh), and three species of predaceous Myxobacteria *Myxococcus virescens, M. fulvus* atnd *Chondrococcus exiguus*). About half of the bacterial species were attacked by any one of these predators. Due to the dissimilarity in the feeding habits of the predators only seven strains were not attacked by any and twelve were attacked by all the predators. Strains of *Rhizobium spp.* were generally resistant to their attack (Anscombe and Singh, 1948). Thus in order to establish any kind of bacetria in soil, it is desirable to find out their resistance to micropredators (see Thornton and Crump, 1952 ; Thornton, 1956 ; Thornton and Meiklejohn, 1957 for references).

NEED FOR FUNDAMENTAL RESEARCH IN SOIL MICROBIOLOGY IN INDIA

I should like to point out that very little work in Soil Microbiology indeed is being carried out in India outside the special field of plant and animal pathology. I have given a brief account of a section of the vast and complex living micro-population of the soil and their activities mainly under the special climatic conditons of the temperate zone. Old concepton that Soil Microbiology is the study of soil bacteria is rapidly disappearing. Unlike the developmental history of Zoology and Botany, Microbiology has had a highly atypical development. Morphology, taxonomy and ecology of micro-organisms in the wider sense has not been properly studied. A systematic study of bacteria, fungi and actinomyces, protozoa, algae etc., and even viruses, that find temporary abode in soil, is important. It is becoming increasingly clear that fertility of soil and plant growth depend largely on the activities of these microbes.

Development of Soil Microbiology has suffered a great deal in the past because Chemists, who were primarily responsible for soil fertility, have been mainly interested in the chemical processes such as oxidation of ammonia and fixation of nitrogen in which certain special kinds of microbes take part. Thus the objective study of the microbes indigenous to different types of soil has been neglected. The Microbiology of Indian and other tropical and semi-tropical soils has hardly made a serious beginning. The problems in Soil Microbiology in India may be diflerent from those in England, the United States of America, Canada and other countries where some good work has been carried out. It is well to remember that in the tropics the organic matter of the soil burns away quicker than in the temperate zone, by the activity of the micro-organisms and, therefore, there is always the danger of soil erosion.

I do not intend to outline the problems in Soil Microbiology in India I personally do not think that it is wise to have pre-conceived ideas about detailed work in Soil Microbiology under the special climatic conditions in India. As very little reliable work has been done in Tropical Soil Microbiology, it would be possible to suggest profitable lines of research when some preliminary work has been carried out to assess the importance of the various groups of soil micro-organisms. The present state is such that no aspect or division of it is free from the urgent need of fundamental research. One could pick out many fundamental problems needing study, each of which should lead to knowledge that would have ultimate practical importance to Indian Agriculture. I think that the lines along which work is needed most are as follows :—

1. A survey of the distribution and numbers of the main groups of micro-organisms in typical soils by known and newer and better techniques.
2. The conditions that make the predominance of useful groups of organisms should be studied both under laboratory and field conditions.
3. Biological mineralization, particularly of phosphorous and iron compounds needs study.
4. Study of the polysaccharides and related compounds, produced by micro-organisms, has a bearing on soil crumb structure and humus formation in soil.
5. The decomposition of crop residues should be studied in collaboration with Chemists.

6. Microbiology of ' Rhizosphere ' and ' Mycorrhiza ' present most fascinating problems in Soil Microbiology and have a practical bearing on the growth of plants and prevention of certain root diseases caused by microbes.

7. *Biological nitrogen fixation.*

Next to water, oxygen and carbon dioxide, nitrogen is the ' major ' plant nutrient that is needed in largest quantity by the crops. The demand for nitrogen is bound to increase owing to rising world population. The resources of industrial power to produce artificial nitrogenous fertilizers are not inexhaustible in the long run. Leaching and denitrification are bound to aggravate this situation. Therefore, the possibility of supplying nitrogen to the soil by biological nitrogen fixation must be thoroughly explored.

(a) It will be of great interest to find out what micro-organisms among the free-living non-symbiotic groups are commonly present in different types of soils in India and it will be profitable to attempt to encourage their growth in their natural habitat.

(b) Study of nodule bacteria has already produced results of practical importance to Agriculture in different countries. In a country like India, where the protein diet of a great majority of people and fodder for the cattle depends mainly on leguminous crops, the study of this group of organisms is of special significance. In order to achieve results from symbiotic nitrogen fixing bacteria, fundamental study of the conditions under which ' effective strains ' will get established in soils where they are lacking or where they could be successfully introduced in competition with the ' ineffective ' native strains is needed. ' Effective strains ' from temperate soils may not find a suitable home in Indian soils.

I have given above an outline of some pressing problems in Soil Microbiology, which have great practical applications in Agriculture. In India these problems have either been completely ignored or are being tackled very inadequately due to the lack of suitably trained personnel. I suggest that a proper beginning be made by starting an All India School of Soil Microbiology consisting of specialists in the different branches of Microbiology and allied Sciences. This will help in contributing to an integrated picture of Soil Science and Soil Conservation. The knowledge so gained may be utilized for practical Agriculture in this country.

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SECTION OF PHYSIOLOGY

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PRESIDENTIAL ADDRESS

APPLICATION OF PHYSIOLOGY IN ANIMAL PRODUCTION

I am grateful to the Sectional Committee for asking me to preside over this session. In making the choice, I take it that you have recognized the growing importance of Animal Physiology with which I am associated. As an Animal Physiologist I am glad of the rare opportunity which this distinguished forum has offered for the initiation of a programme of discussion seeking to integrate the study of man and animals, or perhaps more truly—of man and other animals.

In the study of animal physiology, the stress has largely been laid upon applied research. The quest for knowledge has been focussed on practical applications in the multiplication of species that can be readily and more advantageously pressed into human service, in the larger production of milk, meat, wool and egg and above all, in ensuring a healthy life for animal so essential for maximal output of all kinds. Being an applied science, Animal Physiology has moreover to correlate and co-ordinate the results of fundamental research in Physiology, Biochemistry and Genetics.

Barely half a century ago, the annual milk yield of average cow in dairy countries abroad was about 2000 lbs. Today, the performance of the average cow is in the neighbourhood of 5000 lbs. This phenomenal achievement reflects, since most studies have shown that the heritability played a lesser role, the unique contribution of the science of animal physiology towards productivity. In a brief compass, I shall attempt to unfold before you certain broad aspects of recent developments in this applied science.

REPRODUCTION

(a) *Chemistry and Preservation of Semen*

Reproduction is the basis of all economic productivity. One method, artificial insemination (A.I.), though known many years ago is now being used with scientific refinement of technique for large scale breeding. This mass use of A.I. has naturally led to a great intensification of research on semen ; on its biochemistry, on metabolism of sperms and their fertilising capacity and on preservation of semen with a view to evolve the most economic method of using sperms for reproduction.

Semen is of particular interest to a biochemist as, in addition to inorganic constituents, it contains some unusual organic compounds in high concentrations. Furthermore, they are materials that are to be reckoned with in the consideration of both preservation and fertility of spermatozoa. The inorganic constituents of semen have a pronounced effect on the spermatozoa. In solutions containing potassium the viability of sperms is high. But in media free of potassium or in those freed of potassium by repeated washing, the sperms become readily immotile. Calcium and heavy metals depress viability. Unlike other biological fluids the sugar in the semen of most mammalian species is fructose, and is an important source of energy for the spermatozoa. Its rate of breakdown is correlated with the number of motile spermatozoa and probably with fertility. After castration, fructose disappears from the seminal fluid but reappears after injection of the male hormone ; its concentration can be reduced by insulin. Since neither the testis nor the epididymal secretion contains fructose, the spermatozoa come in contact with it only after being intermixed with seminal plasma during ejaculation. This happens exactly when the sperm must attain a high degree of motility, requiring a source of readily available energy. This energy obviously is provided by fructolysis. Boar semen has been found to contain a large amount of inositol. The important nitrogenous bases found in semen are ergothionine, spermine and choline compounds. Ergothionine may be important in protecting the SH groups of the spermatozoa from inactivation[18]. Free amino acids and citric acid are also present in seminal plasma. Production of the amino acids is, like seminal fructose, controlled by testosterone, since they also disappear upon castration[37].

In a comparative study of semen obtained from various species of animals it was noted that whereas practically the whole of the total reducing substances in ox semen could be accounted for as fructose, in buffalo semen, fructose constituted not more than 60% of the total reducing substances. The semen of these two species vary in many other respects. In a recent study it has been found that the concentration of certain inorganic constituents found in buffalo semen is in marked contrast to that of the other species. Expressed in mg/100 ml semen Ca, Cl, total and acid-soluble P in the two species are 40±2·1 (25±3·2), 373±5·5 (248±2·6), 103±8·9 (47±2·5) and 72±3·9 (29±3·2) respectively. Figures in parenthesis are those of zebu bull semen. The concentration of inorganic phosphorus is same in both, 6 mg. %. By chromatographic analysis, it has been found that the free amino acids present in semen of both the species are same ; the amino acids found are glycine, aspartic acid, glutamic acid, serine and alanine. By employing the same analytical technique the sugar present in buffalo semen is wholly accounted for as fructose[24]. The enzyme contents of the semen obtained from ox and buffalo bull again reveal marked differences. The acid and alkaline phosphatase activity of the latter is very much greater. The respective figures are 308±43·8 (145±11·4) and 251±37.2 (133±14.1) Bodansky units. A very powerful egg yolk coagulating enzyme has been found to be present in the goat seminal plasma. The source of the enzyme is the bulbourethral gland. Like the two other known coagulating enzymes, rennin and thrombin, this enzyme also requires the presence of calcium ions to reveal its activity ; citrate, oxalate or addition of excess of phosphate inhibit the enzyme activity. The enzyme can be extracted from bulbourethral gland with water and such an extract retains its activity in full for over a month if preserved in a refrigerator. Presumably because of the denaturation of egg yolk by the enzyme, invariably present in ordinary semen diluents, goat spermatozoa can not be kept viable for more than a few hours[25]. This enzyme, when added to spermatozoa suspended in media containing egg yolk, has been found to suppress oxygen utilization and within certain limits the degree of suppression is proportional to the amount of enzyme added, but has no effect on oxygen utilization by spermatozoa suspended in saline buffers[26].

The mature mammalian spermatozoon possesses certain unusual characteristics. It is essentially a nucleus functioning without its full quota of cytoplasm. This unique cell is capable of independent motility, but is incapable of reproducing itself ; and performs its chief function, union with an ovum, without any control being exercised by the parent organism. Metabolic studies with spermatozoa are not complicated by cell division or multiplication and, therefore, it is possible to relate metabolic studies directly to cell numbers ; furthermore, the problem of the rate of gaseous diffusion does not limit respirometric studies because the cells are all detached from each other.

Under *anaerobic* conditions spermatozoa produce a large amount of lactic acid from fructose and it is necessary to have an efficient buffer to prevent damage to them due to a shift in pH. Under *aerobic* conditions the need for a buffer is not so great since lactic acid is oxidized[18]. As shown by Mann (1945) 'the glycolytic pathways and enzymes involved in the *anaerobic* metabolism of spermatozoa bear resemblance to those of other animal tissues and yeast. Hitherto, the study of enzymes concerned with glycolysis involved for the most part the use of purified systems separated from the cell structure (for example, muscle and yeast) ; objections were occasionally raised that results obtained in this manner may not depict the true function of those enzymes inside the cells. However, with spermatozoa the course of reactions catalysed by the glycolytic enzymes has been explored in the cells themselves'.[19] In a study on the oxygen uptake by spermatozoa, suspended in the three media, normal saline, Kreb's bicarbonate and phosphate buffer, it has been observed that phosphate ions suppress the oxygen uptake by buffalo spermatozoa. This effect was noted previously with bull spermatozoa. The relative oxygen uptake in saline and Kreb's were practically of the same order. It does not appear that a semen diluent containing phosphate ion would prove useful in the preservation of buffalo semen in vitro[27].

The success of the Russian programme of A. I. initiated by Ivanoff in 1899 created world-wide interest and it became clear that one of the major tasks was the development of better methods of semen preservation *in vitro*. The investigations culminating in the development of the two well known semen dilutors, egg yolk phosphate (EYP) and egg yolk citrate (EYC), can be regarded as the corner stone in the successful application of A. I. in animal breeding[37].

The discovery that has completely revolutionised the artificial breeding industry was the observation in 1949 by Parkes and colleagues that glycerol enables preservation of spermatozoa by freezing it down to −79°C. To begin with, it was found that when bull semen, diluted to contain 10-15% glycerol, was frozen from 0° to −79°C over the space of about 45 minutes, a large number of spermatozoa resumed motility when the sample was thawed. Such semen samples were, however, infertile. Later experiments revealed that if semen cooled to 5°C was diluted with glycerol-containing medium at the same temperature *and then allowed to equilibrate overnight at 5°C before freezing*, it helped to recover not only a higher percentage of motile spermatozoa but that such a semen sample retained fertility without any loss. Although free glycerol can be utilized by sperm and the latter is able to penetrate into the cell, this does not necessarily mean that the life preserving effect of glycerol on frozen semen is dependent upon its metabolism. It is more likely that glycerol exerts its effect mainly through a protective action on sperm colloids, probably owing to its high electrolyte and water binding capacity[22]. The "Parkes-discovery" ranks as one of the greatest in modern research becaues of the great stimulus it provided in diverse fields. The chief advantages of frozen semen are :

(i) sperms can be preserved for years. The longest time that semen diluted in conventional buffers at 4°C can be held for breeding cows and can remain fertile without any appreciable loss, is two or three days, (ii) with frozen semen the possibility exists that about 50,000 cows can be bred to one single bull, whereas the number of cows which a bull can ordinarily breed per year by natural service is below 100, (iii) it will extend nominated insemination ; any farmer can become a pedigree breeder using the semen of the best bull in the world wherever they may be situated and (iv) it will help phasing out A.I., as well as concentrate it in any particular season of the year, for semen can be collected, frozen, banked and used when required.

The various steps involved in preserving semen were developed empirically. In the process, however, the important points which emerged were : (i) whereas high calcium and phosphorus contents acted detrimentally to spermatozoal viability potassium proved essential for retaining it, (ii) the composition of the diluent should be iso-osmotic with seminal plasma and the diluents possess buffering action in a fair measure, (iii) diluents containing higher concentratons of electrolyte were less favourable to sperm viability, (iv) the pH of the diluents should be as near the neutral point as possible and (v) additions of substances which the sperms can metabolise improve preservation.

In the background of the above developments, a 4% solution of glycine was tried out as a semen diluent. Glycine is an amphoteric compound ; an aqueous solution is neutral in reaction and it has good buffering property. It was first reported by Roy *et al*[28], and has since been repeatedly confirmed that a solution of glycine is an ideal diluent for bull semen, in that it preserves spermatozoal viability and maintains their motility for a much longer period than do conventional diluents like EYC or EYP[37].

Till recently diluents for preserving the life of boar or stallion spermatozoa for a sufficiently long time were not known. This objective has, however, been achieved by using glycine as a semen diluent[29]. Use of glycine, has besides laid the foundation for artificial breeding of pigs[23]. It is an excellent medium for maintaining spermatozoal motility of many other species[30]-[33]. Moreover, when added to other diluents, e.g. milk or citrate, glycine enhances their capacity to sustain spermatozoal viability[10, 38]. With the bovine spermatozoa, however, it has been found that although excellent motility is retained, fertility shows a rapid decline after 24 to 48 hours[37]. Here is an instance where the two spermatozoal properties, motility and fertility, are in strong contrast although under normal conditions initial motility is used as an index of fertility. It is indeed intriguing to find a dilutor which is so excellent for maintaining spermatozoal viability and motility but incapable of preserving the fertilizing capacity to the same extent.

I can not but recall in this connection the similarity of this observation with that reported after the first successful attempt of deep-freezing of semen. Deep frozen semen was found to contain motile spermatozoa, but they were infertile. A totally different picture was obtained when after the addition of glycerine, samples were allowed to equilibrate in a refrigerator overnight and then deep frozen. Semen freshly diluted in glycine gives as good a fertility as semen diluted in any other buffer. It follows, therefore, that during the course of preservation something happens, perhaps some unknown metabolite may be accumulating which destroys the fertilizing capacity but does not affect motility or viability. Although spermatozoa were found to oxidise tyrosine, phenyl alanine and tryptophane by means of amino acid-oxidase[18], it appeared that as a sperm nutrient, glycine is an inert substance[30]. Using radio-active glycine, Flipse and Benson offered conclusive proof for the first time that glycine is metabolized by spermatozoa, leading to the formation of formate and glyoxalate. They also postulated that glycine utilization may have a sparing effect on glycolysis[11]. Further investigation showed that less lactate accumulate in diluent containing glycine and that there is present in spermatozoa a glycine-alanine transamination system in which the pyruvate resulting from glycolysis is converted to alanine instead of being reduced and accumulating as lactate[12].

Encouraged by the success of using amphoteric, sparingly dissociable organic compounds like glycine, a few other compounds were also tested ; of these alanine and serine were found to be as good as glycine in maintaining spermatozoal viability[24]. Since addition of glycerol to diluents is an essential prerequisite to deep-freezing of semen, an investigation was undertaken to find out whether a diluent containing sodium-glycero-phosphate (NaGP), which contains a built-in glycerol molecule in it and an aqueous solution of which is neutral in reaction, could be used not only as a semen diluent but also to replace the addition of glycerol. The latter expectation was not realised but incidentally the observation was made that of the various diluents used, a 2% solution of NaGP was the best medium for preserving the viability of goat spermatozoa. A.I. in goats have not been practised because the viability of goat spermatozoa in common dilutors like EYC is not maintained well. Reference has already been made to the presence of an egg yolk coagulating enzyme present in goat semen. It can be removed by washing in normal saline. Washed goat spermatozoa, when suspended in glycine dilutor, have been found to remain motile for over a week. A fertility trial was carried out with 24-hour preserved samples ; the conception rate obtained which was 60%, can be regarded as quite satisfactory[32].

From the standpoint of the physiologist interested in reproduction of cattle, the arificial breeding indusrry has provided a research tool of the greatest value. The physiologist can now study spermatozoa in vitro and learn much about their physiology. He can explore the chemical, physical and microbial characteristics of their natural medium—the seminal plasma, and measure the reproductive capacity of males and study the many factors that influence it. With these facilities spectacular progress in the physiology of reproduction, unthought of during the early years of artificial breeding, has been made.

(b) *Female Fertility.*

The balance between follicle stimulating hormone (FSH) and lutenizing hormone (LH) production by the anterior pituitary varies between different species of farm animals. PSH is high in the mare and LH high in the cow and this accounts not only for their different reproduction patterns, but also for the types of sterility they are most prone to. In the mare oestrus is prolonged owing to the low LH and so injection of LH at the time of mating increases the chances of fertilization by causing ovulation. On the other hand, in the cow and the sheep, LH is high and so ovulation is often caused before signs of 'heat' develop, so that 'silent heats' (ovulation without oestrus) are more frequent in these species[15].

Knowledge about reproductive hormones has been utilized for increasing the natural fertility of the animal in order to lower the cost of production. About thirty years ago it was shown that, if in a rabbit, which was shedding 5 eggs from each ovary, one ovary was removed, then the remainnig ovary shed not 5 but 10 eggs[1]. From this it was concluded that the number of eggs shed depended on the level of a certain substance in the blood and not on the ovary itself. Later it was shown that this special substance (gonadotrophin) came from the anterior pituitary gland. This observation in a way has been the basis on which developments culminating in successful superovulation and transplantation of ova rest. Superovulation can be caused by the administration of FSH and LH to produce many eggs at one time. Egg transplantation is the transfer of these eggs to another female, the recipient. The idea has been that an outstanding cow could be superovulated, the fertilized eggs transplanted to ordinary recipients ; at the rate of one per recipient a large number of offsprings can thus be obtained from an outstanding female. Another possible application of egg transfer would be the shortening of the generation interval. It was found that by giving injections of pregnent mare serum gonadotrophin (PMS) a calf could be made to produce eggs before it was a month old and the eggs could be fertilized[20]. Transplantation of such eggs into adult is being investigated. A heifer begins life with about 75,000 ova in her ovaries, and improved techniques should make it possible to obtain many of these for transplantation into cows of less genetic worth. Egg transplantation has been done successfully in the cow, ewe and pigs, but it requires an operation on both the donor and the recipient[40].

For sheep, PMS has successfully been used to increase the lambing percentage. A vasectomised ram is run with the ewes and 12 to 13 days after oestrus they are injected with PMS and turned in with a fertile ram. By this means the lambing percentage can be increased by about 40% in low fertility breeds and to about 20% in high fertility ones[14]. With larger doses of PMS, a larger number of eggs are shed and up to about 30 at a time can be fertilized. All but the maximum number of young normally produced by the ewe, however, atrophy at an early stage. That this is not due to any defect in the eggs themsewves is shown by the fact that if the fertilized eggs are transplanted, two at a time into other ewes at the same reproductive stage, they develop normally. By this means, genetically good ewes have been made to produce twelve lambs in a season (34).

Unlike rabbit's egg, the fertilized eggs of farm animals have no albumen layer and are, therefore, more susceptible to temperature shock. Attempts have recently been made with fertilized sheep ova to see whether they would live in the rabbit, at any rate for a time sufficient to send them by air. It has been found that if fertilized sheep ova are put into tubes of rabbits in the 2-cell stage they acquire in albumen layer like rabbit's egg and continue to develop to the 8-day stage. If they are taken out and put back into an ewe they continue their development (2).

As pointed out earlier in superovulated animals although the number of eggs shed are many, number of young born are never more than two or three. This early death of fertilized eggs is known by the phenomenon of "embryonic mortality". As early as 1914, Hammond observed a marked discrepancy between the number of corpous luteum in the ovaries and the actual number of viable foetuses in swine, and correctly concluded that a substantial number of fertilized ova did not develop normally (16). Corner's work showed that a count of corpus luteum was a reliable index of actual number of ova produced (9), and it was established that embryonic and foetal mortality was, and still is, a major problem in animal productivity. Twenty to forty percent of the ova produced undergo embryonic and foetal death. A systematic study of anatomical and endocrine abnormalities associated with impaired fertility showed that age at time of breeding and various sequences of full and limited feeding affected ovulation rate and embryonic survival. Uterine environment, especially uterine space per embryo, has also been shown to be of major importance. Recent work suggests that the losses in terms of number of ova produced and lambs born may be as high as 40-60% (15). In cattle, early embryonic death is an important unsolved problem. The characterisation and remedying of these physiological deficiencies is one of the most fertile fields for future research.

PHYSIOLOGY OF RUMEN.

The mechanism of digestion in ruminants is of complex character in as much as microorganisms inhabiting the fore-stomach play an important role in the breakdown of crude fibre. It is now clearly established that bacteria are the chief cellulose digesting organisms and produce a large amount of fatty acids (17). Despite the fact that the mucosa of the rumen has stratified squamus epithelium, the blood draining this compartment is higher in volatile fatty acids than the peripheral blood ; these are absorbed through specialised structures known as papillae present in the rumen wall (3). A considerable proportion of the energy needed by cattle is contributed by the fatty acids resulting from cellulose digestion and milk constituents like butter fat are synthesized out of them[13].

Many microbial stimulants have been discovered ; some of the more recent ones are products such as caproic, *n*-valeric, *iso*-valeric and *iso*-butyric acids which assist in the digestion of cellulose[4]. *In vitro* experiments have demonstrated that amino acids like proline and valine, combined with either leucine or arginine, stimulate growth of rumen bacteria[5]. The many nutrients that are required for maximum bacterial activity and digestion in the rumen is just beginning to unfold.

This aspect of rumen physiology is of particular importance in relation to the conditions prevailing in India. There is shortage of conventional animal fodder partly due to the enormous size of the cattle population and partly to acute shortage of pasture and land to grow cultivated fodder. Situation such as this demands a radically different approach to the problem of cattle nutrition. It would be necessary to tap new sources like dry leaves, saw-dust, waste paper etc., all of which contain cellulose and/or lignin. Intensive research in the field of rumen bacteria and protozoa would have to be undertaken with a view to help evolve new strains of micro-organisms in the rumen or modify those present so that the raw materials like those mentioned above could be utilized by them, giving rise to products which could be used by the host, just as the termite which harbours protozoa utilize the protozoal metabolic end-product, acetic acid, to meet its own requirement. This is not an idle speculation ; biochemists and bacteriologists would have to grapple with the problem with the same intelligence and constructive approach by which the physicists have made it possible to utilize atomic energy for power. Similarly, energy dissipated by the breakdown of volatile fatty acids in the form of methane, carbon dioxide etc. by the rumen bacteria would have to be successfully controlled, to make full use of the gross energy for production. Bacterial nutrition can not be allowed to be left out in any consideration of the problems in cattle feeding which so far has been solely dependent on the science of cattle nutrition.

Climatic Physiology and Animal Production

Various climatic attributes, which include temperature, light, humidity, air movement and radiations from outer space, are known to bring about physiological disorders, ultimately affecting different economic aspect of animal production. Tropical degeneration results in retardation of growth and a marked decline in fertility. The rise in body temperature and respiration rate above normal as a result of high environmental temperatures causes a decline in the yield of the lactating cow ; indeed producing dairy cows manifest greater discomfort than dry cows during hot months. Corresponding with the seasonal fluctuations in both rainfall and temperature the feed value of natural pastures in the greater part of these regions varies considerably throughout the year. It follows, therefore, especially in the event of resrticted or sparse grazing, that the growth rates of livestock feeding on such pastures would fluctuate in much the same manner. During rains and autumn grazing on natural grasses largely helps the physiological requirements of the animals, whilst during summer when shortages prevail a considerable loss in weight occurs. Since reproduction and production are essentially functions of growth, these disturbances necessarily upset the whole physiological balance. In regions with fluctuations in the nutritive value of its natural pastures, in combination with high summer temperatures, the problem of adaptation by the animals becomes more complicated. As the body temperature increases during the hot months the time spent in grazing is reduced and that of lying in the shade increased, the animal suffers from a constant hyperthermia ; no wonder that it virtually exists in a state of chronic undernourishment. Since high production requires high feed intake there is a gradual decline in animal productivity as environmental temperature rises above the zone of thermal comfort[6].

Scientific investigations provided the evidence to prove that the high grade European breeds of cattle, which are the result of selection for maximum performance under temperate climatic conditions, do not maintain the same qualities when transferred beyond the borders of their natural habitat. Hence improvement of animal production by merely replacing the cattle native to tropical and sub-tropical regions with highly improved breeds of temperate origin, may not be a feasible proposition. Crossbreeding between the indigenous stock and exotic types presents another possibility. During the early stages of livestock improvement in tropical regions, a policy of grading up with European breed bulls was particularly advocated. The first generation cross-breds excelled the quality of the indigenous stock, but as the proportion of indigenous blood decreased in subsequent grades, the cross-breds also deteriorated[6]. We now know that the degree to which the offspring of crosses between tropical (Zebu) and European breeds can adapt themselves to hot climates, depends primarily upon the amount of Bos-Indicus blood present in the hybrids, relative to the severity of the conditions ruling. With 50,000 head of cattle available for the cross-breeding programme, it took 30 years before the Santa Gertrudis which was developed in South Texas, could be recognized as an altogether separate breed. Under the sub-tropical conditions peculiar to Texas, approximately ⅜ Zebu blood was found sufficient for the Santa Gertrudis to be adaptable, with Shorthorn constituting the remainder[35]. In South Africa a combination of ⅝ Afrikaner × ⅜ Shorthorn was required to achieve similar results due, it appears, to the more severe conditions of climate[36]. Only the studies in climatic physiology of different breeds can help in the development of high heat tolerant yet high productive breeds. Moreover, in the breeding of livestock for tropical and sub-tropical environment, it is of particular importance to pay attention to the conformational features and breed characteristics which promote adaptability. Firstly, for maximum radiation to be possible, the animal must possess a large skin area. Thus it is a noticeable feature of Zebu cattle that they have a well-developed dewlap which extends down to the navel, together with easily extensible skin folds which are especially numerous in the neck and thoracic regions. Hair covering, which includes the thickness of the coat and structure of the hair fibre, is of equal importance in heat regulation. The critical temperature of smooth-coated cattle lies several degrees below that of woolly-coated individuals. Colour is regarded as playing a role in heat regulation by influencing the amount of sunlight that is reflected from the skin. Earlier studies showed that a light coloured coat is superior to black in the dry tropics. Measurements of the reflection of light from various coat colours indicated that the white hairy coat absorbed but 45 per cent of the solar radiation impinging upon it as against 89 per cent in the case of the black[7]. As for the slower growth and maturing characters of Zebu cattle, these actually are qualities of practical significance and value under varying conditions of climate, and especially of nutrition. As a result of a slower growth rate, the influence of periodic nutritional depressions is not so acute as is the case with the rapidly growing, early maturing breeds of cattle of the temperate zone.

As a dairy animal the buffalo occupies a pre-eminent position in the country. From the limited information available the conclusion is inescapable that the buffaloes are very much less heat-tolerant than the cows. The thickness of the hide and the jet black colour of the skin are two important characteristics which make them heat intolerant. Some important observations on the comparative reactions of the two species of animals to various climatological factors have been reported from the Indian Veterinary Research Institute. It has been shown that the semen quality of buffaloes are more adversely affected due to environmental stresses. The sperm density is low and the percentage of dead spermatozoa is high in semen during summer which is characterised by high environmental temperature and desiccating hot wind blowing at a high speed. The position is further aggravated during hot humid weather[8]. The reduction in sperm density and increase in dead spermatozoa, however, are not as spectacular as those observed by respirometric studies. Spermatozoa immediately after ejaculation show a high oxygen utilization ; but this falls sharply within 15 to 30 minutes and declines rapidly thereafter. The decrease in oxygen utilization cannot be correlated with the percentage of live sperms initially present. Compared to it oxygen utilization of spermatozoa is sustained at a very high level for over two hours when the climatological factors are less inclemental and can be correlated with the percentage of live sperm. Follow up of these investigations revealed that in summer samples, during incubation, there was a heavy mortality in the spermatozoal population which was maximal during the first half hour. This, however, was not the case when semen was collected from the same bulls during more favourable weather. It appears, that although the spermatozoa are alive, they are not quite normal ; something has gone wrong while they were in the body. For want of a more precise term which could express the condition of such spermatozoa the authors have used the word "senile". Like the proverbial last flicker of the candle these spermatozoa exhibit exaggerated motility immedately after ejaculation. Investigations are in progress to determine factors responsible for this *senile* condition of the spermatozoa[27]. The intense solar radiation and the high environmental temperatures during summer months are no doubt contributing factors, but the effects of the heat rays, refleced from the bare sandy soil on which the animals graze or the heated cemented surface of the cattle shed where they rest, impinging on the testes need to be taken into consideration. Investigations have been undertaken to adduce experimental proof in support of the contention that the deterioration in the keeping quality of semen obtained during summer months is to a great extent due to the effect of these reflected rays from the surface on the epididymal spermatozoa, and not spermatogenesis per se.

The information so far gathered on environmental physiology are sufficiently important to take due notice of in the enunciation of cattle development programme and breeding policy to be pursued in this country. Because the climatological conditions in various regions differ radically, a bias for any particular type of breed, or a particular species, is fraught with dangerous consequences. Degeneration in productivity may not appear suddenly ; but when it does, rectification of the mistake would prove to be not only costly but time-consuming as well.

Besides selection and breeding of cattle, specifications of cattle shelter for widely differing climates is also important in the study of climatic physiology of animals. A huge expenditure used to be incurred in Europe and America in maintaining cattle in warm barns. Consequent to the various investigations on climatic physiology, open sheds constructed at much lesser cost have been found sufficient *even at subzero temperature,* provided these sheds were made draught free and bedding of dry hay was given. It has been found that cattle exposed to incresing radiation by lamps are heated to the same extent as hot air having as much heat as the lamp radiation energy[6]. In our country animals would need not only shelter from hot blasts of air, but also shade against solar radiation. Very little attention has been paid to specifications regarding cattle shelter in India although it is recognised that shed and shelter influence productivity. Advantage should be taken of technological advances by which a large segment of environment could be modified or controlled so as meet the requirement for maximum animal productivity.

Marshall first reported that light affected reproduction in birds and sheep[21]. Many investigations emanated from it. One which merits mention is that of Yeates wherein he showed that the breeding season of sheep could be altered by controlled lighting[15].

Adaptive characteristics, such as ears, dewlap, skin colour etc., which harmonize different breeds with their respective climates are recognised on sight ; others such as neuro-endocrine peculiarities are neither apparent nor fully understood. Our knowledge on how environmental changes that are registered on the surface receptors of the orgnaism influence the behaviour of endocrine glands like adrenal cortex, pituitary or gonads, or how environmental changes influence the sensitivity of tissues to different forms of hormonal stimulations is very elementary.

Although the overall productivity potential of animals in this sub-continent is enormous, it must be recognised that the high standard of animal production of temperate countries can never be attained in tropical regions, and also that the indigenous stock of the tropics are inherently of lower productivity than those of the temperate zone. It is of prime importance to appreciate that all development of livestock enterprise in the tropics must necessarily be in accord with the predominantly poorer and more adverse environmental conditions.

CONCLUSION

For sometime past attempts are being made to explore the knowledge of animal physiology as broadly reviewed above in implementing programme of livestock development in India. These attempts undoubtedly augurs well, but in order to derive the maximum benefit the application of the knowledge in the context of countries' resources and variegated conditions requires careful planning. Lest the efforts made are not frittered away in fruitless inconsequence, may I take the liberty to draw attention to certain aspects of present day animal husbandry practices which appear to be groping in a not very clearly lit path.

A.I. of cattle has been in use in the various States of India for over a decade. The enthusiasm and optimism evident in the wake of its introduction has, however, not been fully justified ; not because the practice has not been as widely adopted as in Europe or America but because of the poor achievements. It is common belief but not substantiated by facts that the number of cows conceiving as a result of A.I. is less than what it is by natural service. Secondly, is the observation that viability of zebu spermatozoa in the conventional dilutors is less than what it is with European bulls, and that buffalo sperms do not remain viable to the extent that zebu bull sperms do. Besides these, there are other extraneous factors. As indicated before it would be incorrect to expect that the fertility of the indigenous stock would be the same as that of the European stock. Climatic inclemency, under-nourishment and defective managerial practice are some of the contributing factors which limit fertility level. It is necessary to have our own yard stick to measure it. This can be arrived at by carrying out large scale controlled trials to ascertain percentage of conception consequent to natural service, not only in different parts of the country but also in different seasons. This basic information, so very necessary for evaluation of A.I. programme, is still lacking. It alone can dispel the idea whether or not the A.I. programme launched in the various States is succeeding. Investigators, who have experience of working in this field both here and abroad, could not have missed to observe the difference in the quality of semen ejaculated by the bulls used in A.I. centres in India and countries in Europe or America ; the conclusion is unavoidable that the semen obtained from the indigenous bulls is of inferior quality. No wonder sperm viability in vitro and fertilizing capacity is poor. Without minimising the importance of investigations concerning new and better dilutors for prolonging sperm viability in vitro, more attention should be paid to the bull ; no dilutor can possibly transform an inferior quality semen into a good one. We need to investigate and isolate the various factors which contribute to the production of poor quality semen and lay down conditions conducive to production of good quality semen. Only then could we be sure of the A.I. industry in this country, as well as justify taking recourse to it as the breeding technique of choice.

Cows are bred in this country throughout the year although the percentage of cows coming in heat is more numerous during spring. The frequency distribution tend to show that spring is the natural mating season of cows. Similarly, buffalo cows are bred from July to December although there are two peaks ; the three weeks immediately after the advent of rains and last four weeks of autumn. Efforts should be made to telescope the mating seasons and concentrate the artificial breeding programme to these peak periods only. This is expected to ensure a more even flow of milk, and satisfactory working of the A.I. centres.

Managerial practices require changes taking into consideration the climatic streses the animals are subjected to. High environmental temperature by itself is bad but when accompanied by the twain evil—high velocity wind and high humidity—the result is deterioration in every front—health, production and reproduction, brought about directly or indirectly by limiting the supply of feed and fodder or encouraging parasitic and other diseases. We have a long way to go before we would know how to tackle these problems but the task of finding out will prove immensely rewarding. We are not only ignorant of the "normal fertility" but also of the production potential of the indigenous stock. They are, and would be poor, compared to the European breeds ; however , there is no doubt that with more efficient management production can improve substantially. The limiting factor here is the low plane of nutrition consequent to conditions known to all of us—some of which are man made. If conventional fodders are in short supply, the alternative is to tap newer sources which can supplement it, and/or reduce the number of cattle. In this connection, intensive research in the field of physiology of rumen and measures to control unrestricted breeding of cattle need serious and immediate attention.

Progress in the understanding of the part played by animal physiology in the regulation of animal function, behaviour and production has accelerated rapidly during the past few years. Attack upon the problem has emanated from widely varied sources and many disciplines have contributed their share toward the goal which still seems to lie far in future. I have attempted to outline only the salient amongst the recent developments in research and to indicate some future possibilities in this very important subject. Ladies and gentlemen, I thank you for listening so patiently to this address.

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SECTION OF PSYCHOLOGY & EDUCATIONAL SCIENCES

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PRESIDENTIAL ADDRESS

QUANTUM OF SOCIAL BEHAVIOUR

I thank you all for the honour you have done me by electing me the President of this section this year. I am glad to see before me a good number of social scientists with whom I wish to share my own thinking in all humility, on some vital issues of the day.

To-day we are in the midst of social, political and economic distemper. This distemper so marked is not the peculiarity of any country but it is universal. As a result we find that man today is cut away from the moorings of life. The social value, the religious organisation, the mode of education and other controls of human behaviour have lost their decisive influence and there is everywhere, whether in the East or the West, an utter social disruption giving rise to a number of problems, namely, delinquency, crime, poverty, unemployment etc. in the individual plane and war, strife, mistrust etc. in group life.

Wherever we go we meet with complaints of inefficiency, the fault lies always "at others doors and not at mine". For example, a cloth dealer complains the hoarding of rice by a rice dealer forgetting that he makes the same malpractice with the commodity in which he trades. The office clerk does not do his job properly and at times becomes discourteous to the public. Daily passengers in trains, trams and street buses, show irresistible temper at the slightest provocation or even without them.

These malevolent behaviours flow from the effects of the family break-up. The family which has traditionally been recognised as the primary social unit and the key stone of social organization in different cultures, had been in the past a self sufficient economy with primary responsibility of the young, a focal point of religious training and practices, a citadel of security and protection of its members, a centre for their recreational and affectional life, has now ceased to function as a source of dynamism for the balanced expression of physical, intellectual and emotional life of man.

Social disorganisation of which the disruption of the family is but a causal .core, is an intermediate stage in the process of social change between social organization and social reorganization. In short, the cycle of social change may thus be stated in the line of sequence, organization-disorganization-reorganization. Looking at the spread and depth of social disorganization we may say that we have passed through its peak which now should give place to reorganization as a logical step. This process of reorganization undoubtedly calls for a thorough planning so as to orient human behaviour in conformity with the social norm.

We are now in an industrial era and its impact in our life is a stern reality. We cannot therefore put the hands of the clock back and revert to the stage of pre-industrial era. The physical and economic structure produced by industrialization and urbanization, gave rise to culture changes resulting in the disintegration of personality and behaviour. So our main task would be to reconstruct the social norm of our behaviour conducive to the development of the individual.

In human behaviour, egoism plays as an instrument in the hands of an individual for his sustenance through obstacles. This egoism or attention to self is evident in the newly born child regulating his behaviour in avoiding pain and courting pleasurable situations. But human offspring, as we all know, is the most helpless at birth and cannot exist by himself. He needs tending by a careful, all-loving attention of his mother for a certain length of time so as to protect him from immediate danger. It may be mentioned that the mother tends the child because of the biological position that has occurred in her for bearing the child. The continuance of the life of the offspring is a need to the mother for easing certain physical tensions that last for a period in the mother under such conditions.

The protective feeling of the mother even beyond this period receives additional strength with her male partner in this upbringing process. The parents continue their protection to the child and undergo all sorts of privations as a process of socialisation beyond the biological needs. This mechanism of socialisation can be explained by the fact of training in acquiescence of immediate pain for the sake of deferred pleasure. This is essentially necessary for the integrity of the family. It is clear then that the efforts of the parents in upbringing the offspring is not only egoistic but also altruistic. Altruism here means attention to the bigger whole of which the individual forms an integral part. The presence of altruistic tendency in parents does not occur all on a sudden but must have been latent in them waiting for maturation. The helpless child who shows egoistic pattern of behaviour does also perceive the depth of parental care and attention. It therefore follows that altruistic tendency is latent in the child without which the perception would not have reached the level of recognition. Consequently it may be assumed that a neonate is biologically endowed with both egoistic and altruistic tendencies.

The Russian Zoologist Kessler also stated that the law of mutual aid or co-operation is as fundamental a biological law as that of the struggle for existence. Peter Kropotkin in his 'Mutual Aid' demonstrated this principle convincingly. We find therefore, that the principle of mutual aid and co-operation have been the condition of the survival of the species. This principle led to the formation of collective life and activities in order to ward off destructive forces even before culture and weapons were developed.

History tells us that man lived in various types of associations of which the family is the smallest unit. It also tells us that due to lack of self sufficiency of individual families it led us to go into formation of bigger groups. As a necessary step for ordered life, social laws had to be evolved to regulate interpersonal relationship within the group. Group thus formed, influences moulding the pattern of individual behaviour which also in turn reflects on the group structure with a possibility of change in its configuraton.

So far, we have discussed the way by which human society came into being. In a changing pattern of social structure from the period of primitive communism upto the stage of pastoralisation we find that this age was mainly characterized by lack of private ownership and class distinction. The capacity to produce was at such a minimum level that no one could produce in excess more than his necessities. The volume of production raised by combined efforts of the group was so low that it could not sustain a person whose share of production could be usurped by another, so the social form of exploitation was absent. Hunting, raising of cattle and the primitive agriculture were of such nature that until all the members of the group could put forth combined labour, no single individual could maintain his existence. The contention that stratification of society, private property and exploitation are eternal institutions is therefore unfounded.

Beyond the pastoral age of social development we find that 'might' was considered a benevolent aspect for preserving the herd during its failure to obtain necessary materials for sustenance with proper distribution of the stored food, during that time. The right of distribution therefore went to the persons possessing 'might' within the herd. It is very clear then that these people with might survived during the pressure of the misadventure at the cost of weaklings. In this connection we may cite the example of the mother who does away with her offspring for the sake of self preservation when forced by circumstances. The 'might is right' principle again, gave rise in the world a distinct division of two classes in subsequent period.

To-day with the emergence of the present complex social conditions the characteristics of these two classes are coming to the fore. These two classes are popularly known as masters and slaves or persons dominating and the persons dominated. The classification that resulted from economic and biological conditions was responsible for the fact, that for thousands of years the common men were treated by the ruling class in a manner of utter subjugation. Different substructures came into existence through the distribution of favours by the dominating class according to their own convenience and idiosyncrasies. As a consequence various shades of socio-economic classes evolved in the body of the society.

The nature of these stratified classes suggests that they were based on interest having the strong sense of self-preservation, operating at cross-purposes among groups. Therefore an inter-group conflict was the inevitable result. The complexion of the conflict in this interpersonal relationship springs out of hankering after security. The seeking for security is an urge to satisfy the overall needs of man. When these needs are not fulfilled the seeking does not stop but continue unceasingly.

The very formation of the society throughout the ages was a searching for securing the continuance of the existence of the species in this world against all odds raised by nature and met by men.

Human behaviour in stratified society landed man in inter-group conflicts rather than affording strength to the conquest of nature and the principal urge for security is never lost in man. We witness a large number of evidences of this fact if we examine the different social laws at different times governing inter-group relationship. Here we can again mention the growth of social structure from the days of primitive communism and refer to the present stage of modern corporationism. Corporationism is merely an altered phase of capitalism. The economic principle enunciated by big corporations and cartels have split the very fabric of capitalism that was built on the principle of private property. When the Corporation becomes bankrupt they do not suffer either the financial or the legal consequences of the bankruptcy. They are in effect irresponsible economic barons who arbitrarily manage the public ownership without the responsibility of either a real owner or a Governmental official. These evidences establish without doubt that the right to property as an institution evolved as a defence of the 'haves' against the 'have-nots'.

The privileged class that grew up in the course of historical stage, developed a strong feeling of loyalty to property. Fundamentally the principle that encourages these persons to develop attachment to property is that they have the right to property because of their high qualities distinct from others.

This state of affairs not only gives rise to a sense of superiority and a hatred against the nonpossessed but deepens in them a love for property based on might tantamount to right. In the wake of such a situation we find a behavioural process of these people which bears inviolability of individual differences in natural endowment.

But the unconscious process that was permeating all through these stages has been a hankering for security to satisfy the urge of the "will to survive". The advocates of the principle of individual differences have pinned their faith in the fact that the innate endowments distribute themselves in an heirarchical order of the social status from professionals down to the unskilled labour. Objective tests also demonstrate the fact in similar lines. For instance in intelligence testing we find a number of opinions running counter to each other, some are of opinion that intelligence is an innate capacity and it correlates very highly with successes in life showing a great fund of energy that enables the possessor to attain success. This capacity is immutable in a person who is endowed with it from birth. The critics against this view are of opinion that the materials which formed the items of tests have a culture-bias and consequently those who are privileged, and had opportunities of glimpses of complex life therefore show better standing in these tests thereby proving that the tests are used to find people who conform better to the cultural mores than to innate capacity. If we accept this then the bubble of individual differences stands pricked.

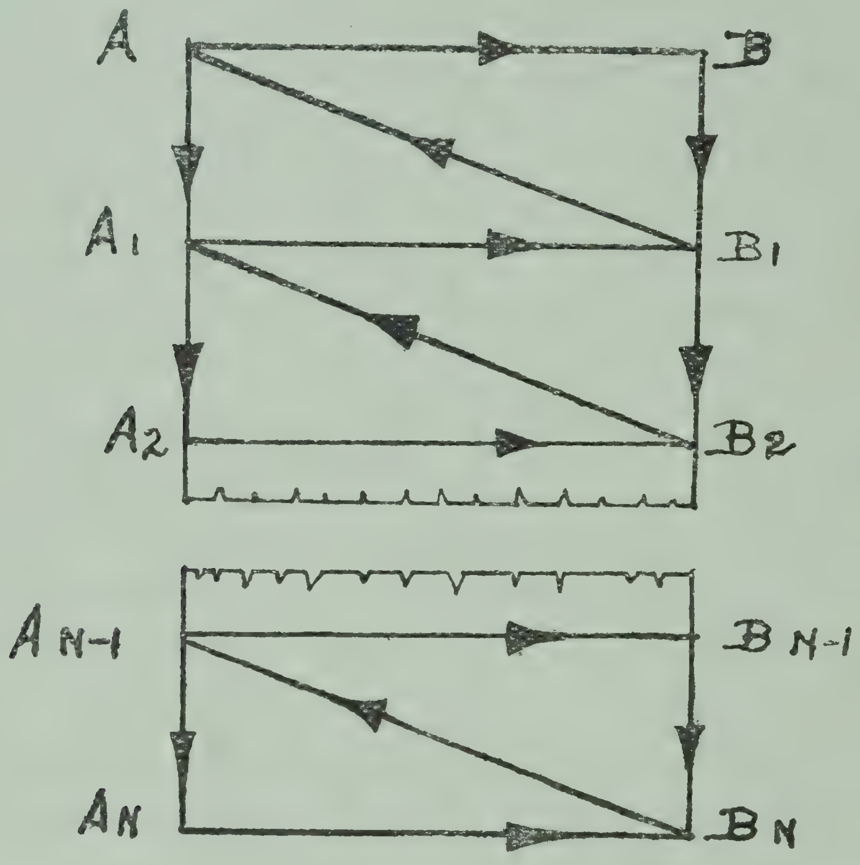
But inspite of it we are in the habit of ignoring reality and adhere to the fact of individual differences as a fait accompli. Accordingly we have structured the social forms in a prejudiced manner and attempt to maintain it with all possible way of special pleading.

We are now thoroughly convinced that individual differences will remain immutable so long as the environmental opportunities are distributed in a graded scale according to the restrictions being severer at the bottom than at the top of the socially determined stratum.

In support we may refer to Harold Laski as follows :—

"The endurance of oppression by Negro slaves was the outcome of the wonted subjection to a regime of privilege. They lost the habit of creativeness, they became in fact those 'animate tools' which Aristotle described as the characteristic of the natural slaves".

On this very premise individual personality matures under limitations of environmental opportunities resulting in various malformations. These malformations have been interpreted by some to be natually imbibed in man rather than derived from social conditions. According to Allport "personality is equal to the function of the interaction of the heredity and environment since every quality is probably influenced by the original determinant inherent in the genetic system and at the same time by the course of life in an actively stimulating environment, it becomes impossible to ascribe with finality any single feature of personality either to heredity or to experience''. On this assumption we find that personality of an individual is an outcome of the influence of the interaction between heredity and environment, of these, heredity being indeterminable, environment appears to be more controllable. Hence if the limitations of the environment continue for a length of period, the personality outcome would naturally reflect in a marked way the influence of the limitation of the environment perpetuated through the ages. The individual differences and the environmental characters and opportunities do influence each other working in a spiral way each changing its character after receiving stimulations from the changed counterpart. For instance, 'A' acts on 'B', changing it to 'B_1', which affects 'A' back to make it 'A_1', 'B_1', receiving again a stimulation from 'A_1', changes to 'B_2, which again affects 'A_1' to change it to 'A_2' and so on.



Our entrenched attitude on the individual differences in the nature of man is therefore nothing but the diehard prejudice and superstition even though the factual reality is so clear. The prejudice and superstitution are so deeprooted in us that they give rise to various complexities of social perceptions ultimately at times leading to a number of social illusions.

Two interesting experiments may be mentioned here to demonstrate social and cultural factors influencing our social behaviours and judgments : In one experiment, a few White American children were asked to state the number of houses between their own and the Railway station. It was found that they did not count the number of houses where Negros lived. In another, conducted by Prof. Bartlett on his Indian and English students illustrates the same point from an identical story narrated to both the groups, the Indian students reproduced the supernatural details of the story while the English students dropped them. Evidently the difference of the Culture patterns of the two groups was responsible for different types of responses. The conditioning factors of our behaviour as demonstrated in these experiments show biases to the social and cultural content of that environment from which the individuals are drawn.

We have so far seen that an individual's personality, more so, his habit and perception are the products of the environment regulating his social behaviour. This behaviour is pregnant with an urge for security. Security in turn means the extent of conquest of the nature.

The material gadgets that are produced in this process, the ideational realizations of abstract forms and meanings in such a context are but the tools which are used for conquering nature. The excellence of efficiency that is reached in these tools measures the height of the culture attained. It would be a travesty of truth to say that many types of cultures thrived at different ages, newer ones rising on the debris of the old. In this connection we may mention that the two usual terms culture and civilization are used synonymously but the term civilisation should be reserved only to specify the height of culture available in a particular region measured by a time period between its rise and fall. For example civilizations of Syria, Harappa, Egypt, Babylon etc.

It is not very difficult to conjecture then that the downfall of such civilizations may be attributed to the lack of participation of the people in the utilization of the boons derived from the particular culture, showing again the helpless conditions of the people in the hands of a few who constitute the upper strata of the society.

The whole matter now boils down to the fact that the very existence of the human society indicates that the individuals have surrendered themselves to the bigger whole with the hope of obtaining lasting security. The hope has never been realized. Because the whole tenor of civilization has been made neurotic by the insane 'gold-rush' of our time. The individual's aspirations were never fulfilled which still await fulfilment through planned work. This concerns us to integrate human personality for ordered life and to reduce the mounting social and psychological problems.

It is now apparent that a new system which will ensure a redistribution of the benefits of culture between the present 'haves' and 'have-nots' based on equality and social justice should be adopted.

The history of man-in-society reveals that man has raised a 'frankestein' in giving shape to social form in so much as that the society which man wanted to build for security did not come up to his expectation ; on the other hand it brought in a number of oppressive features that blockaded the fulfilment of his aspirations.

We have already examined the forms of social laws that were formulated to regulate and govern interpersonal relationship within the bigger whole at different ages. The change in the laws that we notice is an evidence of 'trial and error' always trying for a solution.

To quote Prof. Allport again "Thus there are many ways to study man psychologically, yet to study him most fully is to take him as an individual. He is more than a bunddle of habits more than a nexus of abstract dimensions more too than a representative of his species. He is more than a citizen of the state, and more than a mere incident in the gigantic movements of mankind. He transcends them all. The individual striving ever for his own integrity, has existed under many form of social life—forms as varied as the nomadic, feudal and capitalistic. He struggles on even under oppression, always hoping and planning for a more perfect democracy where the dignity and growth of each personality will be prized above all else". In these lines we can very well read the recognition of individual's personality and his aspirations as the most important aspect of consideration in relation to complex social situation. In order to give individual his due importance, I think we should base our standpoint on reality rather than depending on our older prejudices, superistations or beliefs in innate individual differences, possessive instincts etc., in the nature of man. The great contemporary poet T. S. Elliot has very aptly rhymed this state of our fixation in the matter of our thinking in "Choruses from 'The Rock' ": "Where is the knowledge we have lost in information? Where is the wisdom we have lost in knowledge?" The poet is pained to observe that man is enamoured of baser values than with higher one like wisdom. We have also noted in our previous discussions that the purpose of our constituting the society for obtaining security is far away from us because we have become engrossed in the means to an end rather than to the end itself. We know that biological needs, aspirations etc., are universal in man. The physical amenities that are the gifts of human culture are the birthright of every individual. So the social order should be so organised as to provide equal opportunities to every individual for sharing the said benefits. The right to equal opportunities should not be embodied only in the cold print of the constitution, but social forms should be so organised that opportunities would come to every individual equally and automatically.

This reorganization can be brought into effect if we reduce social distance to as minimum as possible. The physical amenities give objective understandng of superiority, the absence of which brings in a sense of inferiority resulting in all sorts of emotional conflicts, debasing the sense of values in our modes of expression through behaviour. An experiment in evidence is in point: When hunger remains unsatisfied,and the threat of hunger continues, this deprivation may disrupt the social habits of the individual, the person becomes preoccupied with food and 'good manners' i.e. self-control, restraint, decency etc., become meaningless to him. It is noticed that the subjects at the starvation experiment at the University of Minnesota showed symptoms of anxiety, lack of patience, indiscipline, etc. and licked their plates for the last trace of food. They did not stop there. They went beyond in stealing bits of food for the next day. The behavioural expression of these people are but 'experimental' responses and not 'natural' ones. They were chosen from among the teachers, students and scholars of good standing in the society.

The commonness of amenities enjoyed by individual creates a sense of equality in the social status and engenders similar behaviour, thereby minimizing social distance to a great extent. The result of such a position would naturally lead to a greater identification with the bigger whole having more or less uniform characteristics among the participating units of the bigger whole, because we all know that similarity and proxmity are the essentials for the process of identification and belongingness. These essentials are amply justified by the 'gestalt' experiments in perception of belogingness of lines, dots and other objects.

Moreover identification leads to better participation in affairs which are brought into existence for utility of the bigger whole. An opinion survey which is still in the process of study in Calcutta, on the State Transport Organization issue, reveals from the pilot project that only 13% of the personnel in the service of the Transport Organization, feel some what identified with the organization, 6% show very high attachment to the organization and the rest responded in a manner showing absence of identification. Similarly, among the people having the transport utility, it was observed that 21% was in the first category (i.e. some what identified), 13% were in the second (i.e. high attachment) and the rest apathetic.

Examining this result we may conclude that this apathetic attitude towards the organization by the personnel in service as well as by the public in general is the cause of economic loss in earning and in property of the said organization. Had participation been heightened in the personnel as well as in the public, the said organization would have run on an efficienet economic background. Identification with the organization and the management is the only means of heightening both the active and passive participation.

The guarantee to equality of opportunities and the uniform social situation will help to diminish the probability of emotional outbursts and attitudes such as jealousy, hatred mistrust etc. At the same time it would not be difficult to cultivate social qualities viz., love, fellow-feeling, comradeship, etc. essential to make the society more enduring. Consequently the disrupted family, that we have today, will be rehabilitated and will afford a congenial ground for the building up of integrated personality of its members.

Social institutions, controls and modes of education—general and cultural—that are prevalent now should continue to be essential to guide human thinking and behaviour in order to keep things in the line.

The outstanding leaders of thought of the world today are of opinion that it is inevitable to have an all-world Government for lasting peace. The philosopher Lord Russell while answering a question on his new book 'Wisdom of the West', according to the press release of the P.T.I. dated 6th October, 1959, said, "War will only be abolished by a world Government which had a monopoly of all important weapons of war. American-Russian alliance is a possibility and not a probability . . . ." This world Government is only possible if we can expand our 'Self' to accomodate and tolerate different cultures of the world. This means that our behavioural mode should be reoriented from egoism to altruism and that is possible only when a standard and uniform social conditions prevail within a particular culture. Such a situation will release a large amount of energy from action now being spent in overcoming various resistances that we encounter in our modern day-today social existence and the free energy thus available would be utilized for social endeavours in conquering nature for the survival of the species.

Although we all realize the necessity of one world organization as a panacea for social and economic disorders, we cannot go any step further to achieve this goal. The reason is not very far to seek. We know the remedies but we avoid to get into the root of the matter. For example, we have been able to find out the reasons of industrial conflicts by using highly specialized techniques in our experiments but still the industrial strifes are continuing without showing any signs of resolving.

As it is today, the behaviour of the individual cannot be predicted even with the help of very precise scientific tools devised so far. Our social behaviour depends on efforts which are variable according as the situation is encountered. Even in the case of a situation repeating itself the effort put forth by an individual may not be of equal value on the subsequent occasions. This variability is due to a goal-set determined by the perception of the situation and his involvment depending on his biological needs, drives, levels of aspirations, etc. This postulation may be represented by the following equation :

$$e = c\int_{0}^{\alpha} g.di \quad . \quad . \quad . \quad . \quad (1)$$

Where 'e' stands for effort
'c' ,, innate capacity
'g' ,, goal-set
'i' ,, involvement

The level of involvement of an individual determines his goal-set. If each social event has an unalterable meaning to an individual then the variability of his 'i' would tend to be nil and his goal-set would emerge with the same potency at every occurrence of the event reducing the equation (1) to e=c.g. . . . . (2) 'c' is determinable and has been accepted, at least for all workable purposes, as constant for an individual. If we can develop precision instruments for measuring 'g', then 'e' for an individual involved in a social event can be worked out by substituting the values of 'c' and 'g' previously determined, in the equation (2).

In analogy with the physical sciences, of course with a little stretched concept, this 'e' in psychology appears as a quantum of participation in a social event. To maintain the characteristics of constancy and to obtain the optimum value of 'e' for being effective in yielding a social behaviour according to the desired norm, social distance requires to be reduced to a minimum giving rise to unalterable social perceptions. It is needless to say that the efficient diagnostic devices obtained so far, and those, that would be developed in the course of scientific advances would continue to play their roles in order to check the conduciveness of the social climate for producing 'e' with an optimum value for social behaviour.

I am conscious of the limited role of psychology in this process of social reconstructions. Other disciplines have their own roles to play in in this matter. But psychologists, who know how human mind works and under what conditions, have a special responsibility. It is they who should highlight the required conditions for producing healthy social responses and it is they who should give a clarion call to scientists of other disciplines for co-operation and co-ordination for pulling their resources together to achieve that coveted goal.

May I therefore request my colleagues in psychology to contribute their efforts for social building where the climate would be such as to ensure the individual security in order to reorient his outlook from egoism to altruism? This is the only solution as I can look at it for the lasting peace and harmony to guarantee the continuance of the existence of our species in this world.

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PRESIDENTIAL ADDRESS

DEVELOPMENT OF IRON AND STEEL INDUSTRIES IN INDIA

INTRODUCTION

I express my sincere thanks to you all for electing me to the office of the President of the Engineering and Metallurgy Section of the 47th Session of the Indian Science Congress Association at Bombay.

As one who was associated with the metallurgical industries and later with the development of engineering education in general and metallurgical education in particular for over 35 years it was somewhat difficult for me to select a suitable subject for this address which may be of some interest to you. Due to the emphasis that has been rightly laid on the development of industries in the Second Plan period and the vital rôle that iron and steel have to play for this development, I propose to lay before you some aspects of the development of iron and steel industries of this country with particular reference to some of the recent trends and also the effect that a coordinated iron and steel research actually can have on the quality and quantity of production from a given unit in this country. It is not necessary here to indicate details of the history of development of iron and steel industries in India. But no address on iron and steel industry in India can be complete without a reference to the first successful pioneer in this industry, the Tata Iron and Steel Co. Ltd. It is indeed a happy coincidence that the address on the development of iron and steel industries is being delivered at the great city of Bombay where more than fifty years ago in this very city the idea of starting an iron and steel industry in India was first conceived by the late Jamshedi Nasserwanji Tata who was one of the greatest industrialist and philanthropist of our country.

THE TWO FUNDAMENTAL ASPECTS OF THE INDUSTRY—THE TECHNOLOGICAL AND THE HUMAN

A large and complex industrial organisation like an iron and steel plant has fundamentally two important aspects—

A. Operation and maintenance on the one hand and research and development on the other—this in short may be called the '*Technological Aspect*'.

B. Management-labour relations, welfare and other essentially non-technological features may be regarded as the '*Human Aspect*'.

Both these aspects—the technoligical and human—are inter-woven in the entire fabric of the industry and are equally essential for its maintenance and growth.

A. The Technological aspect in a broad sense consists essentially of two parts, (a) the Routine and (b) the Research.

(a) The Routine part implies day-to-day and round-the-clock running of the plant with the object of getting maximum rate of production with minimum cost and involves considerable alertness and strain on the part of the management and a considerable sweat and toil on the part of the workers and supervisors. The nature of the job (requiring hard physical labour) and the environment (usually hot and humid) where it is carried out, hardly allow sufficient time (or energy) to the executives and operatives to think about any improvement of the plants or processes.

(b) The Research part essentially consists of day-to-day and sometimes round-the-clock thinking over fundamental problems and carrying out investigation for finding solution of operational troubles, introducing modifications in the existing practices and inventing new ones that may lead to higher rate of production and better quality of products.

Both these aspects—the Routine and the Research—are equally important, and in recent years the Central Research and Technological Laboratories attached to modern iron and steel plants are, therefore, entrusted not only with the routine of quality and process control, testing, and inspection of the plant but considerable amount of research and development work on plant problems. The research work comprises investigation on raw materials, refractories, causes of rejection of metals during manufacture, causes of failure of metals in service and development work on improvement on existing processes and discovery of new processes. The emphasis and importance laid in recent years on the Research aspect are evident from the fact that Heads of Research and Development Departments are often drawn into discussions on top policy decisions and in many cases are full members of the Board of Directors. While this has not been possible so far in this country, it is time that serious thought be given to this matter so that the development of this basic industry may proceed in the right direction. At the meeting of the National Development Council held in New Delhi on January 7, 1956, the Prime Minister had very rightly remarked[1] :

> "I think that Scientific and Technical Personnel should be introduced not only in Technical Processes but in Administration also. The Administrator is an able man and does a good deal, but his thinking is on different lines than that of a Technical man. I think there should be greater inclusion of the type of thinking even in our administration and it is better to mix the pure Administrator with the Technical man and the Scientific man. After all the problems to-day are problems of Science and Technology. An able Administrator or an able politician, just like an able lawyer, can grasp the main problem to argue this way or that, but it is one thing to argue from the broad outline and another to have grown up with that idea in the process. I think, therefore, that Scientists and Technicians should be associated more and more with various processes including Administration and Planning".

During this address at the Indian Institute of Technology, Kharagpur, the Prime Minister said[2] :

> "There was a time when Administrators played the primary rôle in the country's Government and development but the time has now come when the Engineers play an infinitely greater rôle than anybody else".

B. The Human aspect of the industry like the Technological aspect may also broadly be looked upon to consist of two parts—"Duty" and "Dedication". Even an unskilled workman will regard his work as "Duty" and not an imposed task if he is made to feel the dignity of his labour by allowing him to share some responsibility and profits for his labour. When he becomes conscious that in a sense the industry belongs to him he will think twice before striking work. "Dedication" implies devotion of the self to the pattern of our culture and heritage which we may justly be proud of and which need be revived in formal courses of instructions and by personal example, influence and sympathy of the management from the topmost level downwards. Most of the troubles in the Human aspect of the industry stem from lack of sympathy for and appreciation of the fundamental desires of the human being just as most of the troubles in the Scientific and Technological aspect of the industry arise from a lack of knowledge of the fundamentals of science itself. Large volumes of literature have been written on the subject of 'Management and Labour Relations' and allied matters and it is not necessary for me to dilate further on this subject except to stress the fact that no matter what emphasis be laid on the technological aspect of the industry, the rate of production cannot be accelerated without a corresponding emphasis on the human aspect. I quote here Mr. Benjamin F. Fairless[3], President of the United States Steel Corporation :

> "With all expectations of accomplishments in technology, we feel certain that human values will continue to be placed above all else. The most important part of every company still will be its people. Management's recognition of this fact will be reflected in *progress in human relations fully as important as progress in science and technology*".

In this country where the State is geared up to a socialistic pattern of economy, it is very much desirable that emphasis should be laid on both the Human and Technological aspects which can alone engender favourable climate for maintenance of and improvement on the rate of production.

RATE OF PRODUCTION AND MODULUS OF PERFORMANCE

Of the hundred and odd elements known to man to-day, iron is the one single metal that has played the most vital rôle in shaping his destiny and steel the one single alloy that is at the base of man's all industrial adventures. Practically everything that one could think of is either made of or made through iron and steel and 'to-day it is almost literally true that every product used by man requires steel somewhere along the line'. In her effort to create more wealth and fight hunger and unemployment, particularly in the face of a progressively increasing population, this country, in co-operation with friendly nations, has launched on the great task of, the great adventure of building, and building as fast as she possibly can, her basic and crucial industry of iron and steel. In this great task, the number of iron and steel producing units and the maximum speed of production with the minimum strain on foreign exchange should have equal importance. A large production rate imposes considerable "stress" on almost every facet of the planning (material, technical or human) within the country and also produces considerable "strain" on its foreign exchange particularly at the initial stages. But the objective should be to cut down the strain on foreign exchange while maintaining or even accelerating the tempo or stress of production. The ratio of stress and strain in a given material, as you all know, is the modulus of elasticity of that material. The ratio of the stress of production to the strain on foreign exchange may thus be taken as the measure for the National Modulus of Permormance of a given industry in a given period of planning. For the Second Plan period the modulus of performance for the steel industry is bound to be low due to heavy strain on foreign exchange and lower initial production rates. Assuming that the total production of iron and steel during the Second Five Year Plan be about 6 million metric tons and the foreign exchange involved be Rs. 400 crores, the modulus of performance comes to only 1·5 Kgm. per rupee. I am drawing attention to this figure on the eve of the Third Plan period so that we can bring about an appreciable reduction in the foreign exchange strain by creating well-planned establishments for improvement of Design and Construction and for Development and Research Work at suitable centres. In this connection the decision to start an Iron and Steel Design Section has been a correct one. I have no doubt that the installation of such centres for Research and Development will considerably help increase the modulus of performance by showing ways for cutting down wastes, improving quality, increasing production as well as by indicating the right direction for future development of the industry with the use of indigenous materials and adoption of newer processes of making and shaping steel. Determination of metallurgical loads on furnaces, performance of processes, and quantity-quality control of finished and semi-finished products will also lead to better efficiency.

I have attempted to describe briefly in the following sections some of the essential features of the different steel plants in India. But before this is done it will probably be helpful to know some of the fundamental principles underlining the process of making iron and steel.

SOME BASIC IDEAS OF IRON AND STEEL MAKING

Iron occurs in nature in the form of compounds—the most important of which is Ferric Oxide ($Fe_2 O_3$). Iron ore contains not only iron bearing compounds like Fe_2O_3 but other impurities like silica (SiO_2), clay (Aluminium silicate) etc. Some fluxing materials like limestone ($CaCO_3$) or dolomite ($CaCO_3$, $MgCO_3$) are added so that the basic oxides (CaO, MgO) derived from these fluxes may combine with the acidic gangue of the ore and ash of the coke to form a fusible silicate called slag which may be easily removed from the furnace. Coke is added to supply heat to the furnace by combustion with air and also to form CO which together with carbon reduces the ferric oxide to iron. Iron on melting dissolves carbon almost to saturation (3.5 to 4%) and also other elements like Si, S, P, and Mn derived from the reduction of different compounds. In blast furnace for every ton of iron produced it is necessary to charge nearly 1.8 tons of ore, 0.9 tons of coke, 0.5 tons of stone and 4 tons of air. By controlling the ratio of ore plus stone to coke (called burden) the blast furnace Manager controls the temperature and composition of slag and pig iron which is broadly classified as foundry pig (usually of high silicon contents) suitable for foundry purposes and basic pig (about 0.6 to 1.6% silicon) suitable for conversion into steel by the basic process.

All steel making processes involve oxidation of the impurities (C, Si, Mn and P) in pig iron either by blowing air with or without oxygen-enrichment into bottom-blown Bessemer converter or by introducing pure oxygen into a top blown L-D converter or by charging iron ore and mill scale (Fe_2O_3 or Fe_3O_4) into an open hearth furnace which may be basic (lined with magnesia) or acidic (lined with silica) depending on the nature of the process. The nature of steel making process depends essentially on the phosphorus content of the pig iron. Phosphorus in pig iron is removed as calcium phosphate by oxidation of the phosphorus in the pig iron to P_2O_5 and its subsequent neutralisation by CaO which can be added only to basic furnaces. Since most of the pig irons from blast furnaces contain phosphorus, most of the steel making practices are therefore basic.

Although the basic open hearth process is highly inefficient from the point of view of the rate of heat or/and oxygen input, it has considerable flexibility as regards the raw materials (such as nature of scrap and pig iron and their relative quantities, availability etc.) and also the grades of steel to be made. Hence 90% of world's steel are still made by the basic open hearth process. In recent years, however, the Linz-Donawitz or the so-called 'L-D' process is being increasingly used in several countries on account of its many advantages. The L-D process will be used for the first time in India at Rourkela.

The molten steel from the furnace is carefully cast (by "teeming") into blocks called steel "ingots". The solidified ingots are then reheated at a given rate for a minimum period of time (called "soaking") in pit-like furnace called "soaking-pits". The hot ingots are then rolled in Blooming Mills to produce different square or rectangular sections called "Blooms" and also thick slabs. The blooms after reheating (sometimes without reheating) are then fed into either Sheet Bar and Billet mills or Structural mills and the slabs into Plate mills. The Sheet Bar and Billet mill produce such semi-finished products as sheet bars for further working in the sheet mills and billets which are used in the Merchant mills. The rejected portions from different mills form a substantial portion of the steel scrap which is fed back into the steel melting furnaces.

The Rolling Mill is by far the most costly equipment of a steel plant and considerable care and judgment are necessary in the design, lay-out and operation of the Rolling mills to minimise scraps and rejections. Similarly, considerable care and judgment are necessary not only to produce good steel but to produce good ingots. A good steel made in the furnaces may be spoilt during teeming with the production of bad ingots. Similarly, good ingots may be rolled into bad semi-finished and finished products unless proper care be taken during soaking, reheating and almost during every step from the making of the steel to the rolling of finished sections. The necessity for organizing a strong team of men for metallurgical process-control from the early stages of iron and steel making to the final stages of rolling to finished or semi-finished products can hardly be over-emphasized particularly because the success of our industrial planning will greatly depend on the speed of production of iron and steel of good quality.

GROWTH OF STEEL MAKING IN INDIA AND SOME OTHER ADVANCED COUNTRIES :

Before the Second Five Year Plan, the steel production of this country was about 1.3 million tons. After the Second Plan period, it is expected to be about 5.0 million tons—an increase of about 300% within the brief period of five years. This is something unique in the history of development of iron and steel industry in any country. U.S.A. has increased her steel production by 100 million tons in about 100 years. The fastest rate of increase so far has been in U.S.S.R., where the production of steel has increased by about 40 million tons or nearly 600% in about 25 years. Compared to this figure an expected increase of 300% in 5 years for an industrially undeveloped country like ours would be really creditable, particularly as at the initial stages of building the three new plants in the public sector with their location in unindustrialized sites skilled labour, housing accommodation and transport facilities have not been available to the desired extent. Almost everything had to be improvized and all supplies, equipments and labour and raw materials secured from different places, sources and distances. The hardship undergone by men building the plants under the blistering heat of a tropical sun specially during the summer months can better be imagined than described. Despite these difficulties one cannot but be impressed with the enthusiastic activities of the workers at the three new steel towns (Rourkela, Bhilai and Durgapur) each of which is scheduled to produce a million ton of steel ingot per annum.

TABLE I

PRODUCTION IN MILLIONS OF METRIC TONS

	1955	1960 (anticipated)	Increase %
U. S. A.	106	135	27%
U. K.	20	26	30%
U. S. S. R.	45	68	50%
India	1·3	5·0	300%

While detailed descriptions have been published elsewhere, I am giving below some of the essential features of iron and steel plants of this country.

(A) THE TATA IRON AND STEEL CO. LTD., JAMSHEDPUR[4]

The original plant at Jamshedpur with an ingot capacity of 100,000 tons per year, consisted of a battery of coke-ovens, two blast furnaces, one steel melting shop, a blooming mill, a rail and structural mill and a bar mill. After the First World War, the plant was expanded to an annual capacity of 450,000 tons of ingot steel. With further additions to the plant over a period of years, the Steel Works, during the Second World War, achieved a peak production of 1,237,000 tons of pig iron, 1,082,000 tons of steel ingot and 839,000 tons of saleable steel. The plant, in fact, was overworked during the Second World War and a 'Modernisation and Expansion Programme' was undertaken to renovate it and raise its capacity to 1.3 million tons of steel ingots. Into this was dovetailed in 1955, a new expansion programme, the two together being designed to raise the output of the Works to two million tons of steel ingot per year.

Some of the essential features after expansion are given below:—

(1) The four batteries of coke-ovens will have 256 ovens capable of carbonising 6800 tons of coal producing 4400 tons of furnace coke per day.

(2)(a) The Sinter Plant, the first of its kind in India will produce 2500 tons of sinter per day.

(b) Six Blast Furnaces (one with high top pressure—the first of its kind in India) are expected to produce 6270 tons of pig iron per day. The 'F' furnace with 40% sinter burden may produce 1800 to 1900 tons of metal per day.

(3) Steel Melting Shop consists of the following units—
Old Steel Melting Shop No. 1—This will probably be discarded except 2 or 3 furnaces.
Steel Melting Shop No. 2—Three 250 tons tilting furnaces with three 25 tons converter will produce about 7,00,000 tons of steel per year.
Steel Melting Shop No. 3—Seven 200 tons fixed open hearth furnaces with three 30 tons converters and two 800 tons mixers are expected to produce 1,285,000 tons of steel per year.

(4) The Rolling Mills consist of the following units—Two Blooming Mills consisting of one 40″ and another new 46″ mill. The Soaking Pits—one (new), Two Sheet Bar and Billet Mills—(one new), one Rail and Structural Mill, one medium and light structural Mill (new), one Plate Mill, one Sheet Mill, one Merchant Mill, one Skelp Mill, one Sleeper Plant, one Wheel Tyre and Axle Plant.

The existing 40″ Blooming Mill will roll 950,000 tons of ingots into 827,000 tons of blooms of which 324,000 tons will be diverted to the Rail and Structural Mills and 450,000 tons will go through the Sheet Bar and Billet Mill No. 1 to the Skelp Mill and Merchant Mill and 53,000 tons to the Plate Mill.

The new 46″ Blooming Mill will process 1,050,000 tons of ingots into 917,000 tons of slabs and blooms, consisting of 77,000 tons of slabs for the Plate Mill, 30,000 tons of blooms for sale, 10,000 tons of blooms for axles, 30,000 tons of wheel blanks, 705,000 tons of blooms for Sheet Bar and Billet Mill No. 2 and 65,000 tons of slabs and blooms for the Medium and Light structural Mill.

Between the new 46″ Blooming Mill and the existing 40″ Blooming Mill, the total primary rolling capacity is about three million tons ingot per year.

(B) THE INDIAN IRON AND STEEL CO. LTD., BURNPUR[5]

The Company has two works one at Kulti and the other at Burnpur. The Kulti Works of the Company is the oldest unit in India producing pig iron and coke by modern methods. This Kulti Plant consists of the following units:

(1) Two old blast furnaces (approximate annual capacity 2,50,000 tons of pig iron).

(2) One Coke-Oven Plant consisting of two batteries (annual output about 120,000 tons of coke).

(3) The batteries are equipped with bye-product plants to recover gas, coal tar, ammonia and crude benzole.

(4) One iron foundry (largest in the East) consisting of five separate sections, namely (a) The general Casting Foundry, (b) The Vertically Cast Pipe Foundry (pipe upto 60″ dia.), (c) The Light Casting Foundry, (d) The Spun Foundry (most recent of its kind in the East with annual capacity of 150,000 tons of pipe of 3″ to 27″ dia.), (e) A mechanized Non-Ferrous Foundry (Casting upto 3½ tons).

The works, however, are being dismantled, but a well equipped and modern steel foundry is under construction and will go into production towards the end of this year.

Under full production capacity the Kulti Works will produce annually about 2,50,000 tons of castings (i.e. an increase of nearly 120% over previous production).

The *Burnpur Works* consists of the following units:

(1) Five Coke-Oven Batteries (two new 1957-58) producing 1.6 million tons of coke per year and a Bye-product and Contact Acid Plant.

(2) Four Blast Furnaces (two new)—Annual capacity, 1.3 million tons.

(3)(a) Three 25 ton converters (one under construction).

   (b) One 900 ton Inactive Mixer (Coke-oven gas fired) and another Mixer under construction.

   (c) Three 225 ton Basic O.H. Tilting Furnaces, one 90 ton Fixed Furnace, one 350/400 ton Furnace, two 250 ton Furnaces (under construction).

(4) Rolling Mill—(a) 40″ Blooming Mill (1.0 mill. tons per annum), (b) 34″ Section Mill (0.27 mill. tons per annum), (c) 18″ Section Mill (0.12 mill. tons per annum), (d) Morgan Sheet Bar and Billet Mill (0.6 mill. tons per annum), (e) Sheet Mill (0.12 mill. tons per annum), (f) Merchant Mill (0.18 tons per annum) under construction.

The annual capacity of production after the extensions are completed at Burnpur will be, 1.3 million tons of pig iron, 1.6 million tons of coke, 1.0 million tons of steel ingots, 0.8 million tons of saleable steel, 68,000 tons of coal tar, 22,000 tons of ammonium sulphate, and 25,000 tons of sulphuric acid.

The break-up of saleable steel will be blooms 10,000 tons, billets 1,40,000 tons, rails 1,05,000 tons, structurals 2,65,000 tons, bars 1,60,000 tons and sheets 1,20,000 tons.

(C) MYSORE IRON AND STEEL WORKS, BHADRABATI[6]

This plant (originally called "Mysore Distillation and Iron Works") which started operation in 1923 had a charcoal blast furnace of 50 to 60 tons capacity per day and a Wood Distillation Plant of 200 tons wood per day. Subsequently the blast furnace capacity was increased to 80 tons per day and a pipe foundry (30 tons per day), a steel plant to manufacture 600 tons of steel per week (100 tons per day), a cement plant, output 60 tons per day, a ferro-silicon plant of 6 tons per day, and a rod and strip mill (for wire rods and bailing hoops, output 30 tons per day) were added.

In the second phase of expansion after the Second World War the following additional plants were set up:

> Electric Pig Iron Furnace (60,000 tons) with increased production capacity, Ferro-silicon Plant (5,000 tons), Acetic Acid Plant (600 tons) (Also expansion of Foundries, Tramways and Cement Kilns).

The following projects have been approved for the Second Five Year Plan: Expansion of (1) steel producing capacity to 100,000 tons, (2) Ferro-Alloy Plant (Fe-Si, Fe-Mn, Fe-Cr, Fe-V etc.) to 25,000 tons, (3) Stainless Steel Plant to 15,000 tons, (4) Tool and Alloy Steel to 2,000 tons, (5) Foundries etc., (6) Spun pipe and Sintering Plant.

The first Electric Smelting Blast Furnace (first of its kind in India) went into production in 1952. Another was commissioned in 1956. The daily output from each is about 110 tons.

Some details of the three projects of the Hindustan Steel Ltd. in the public secetor are given below.

(D) ROURKELA STEEL PROJECT[7]

Rourkela is about 257 miles west of Calcutta on the Bombay-Calcutta route of the S.E. Rly. The decision to locate a Steel Plant at Rourkela was taken on account of its proximity to high grade iron ore at Bonai (located just 50 miles to the south), availability of limestone and dolomite in the Birmitrapur-Hathibari area (about 20 miles to the north) and manganese ore in the nearby Orissa mines, availability of water from the Brahmani river and power from Hirakud. Unlike other steel plants in the public or private sectors, the Rourkela Plant has the following special features:

(i) It will have a fast modern continuous Strip Mill—the first of its kind in India and is designed to produce plates, sheets, strips and similar flat products ;

(ii) The major portion (about 750,000 tons) of the steel will be made by the new L-D process—its first use in India (see details indicated later) ;

(iii) There will be a 'nitrolim' fertiliser plant using the bye-products of the steel plant.

The main sections of the integrated iron and steel plant are (i) Coke-Oven and Bye-Product Plant, (ii) Blast Furnace Plant, (iii) Steel Melting Shops, (iv) Rolling Mills, and (v) Development Control and Research Laboratories. Some other details of the plant and its production capacity have been indicated in Table II.

(E) BHILAI STEEL PLANT[8]

The considerations which led to the location of a Steel Plant at Bhilai were availability of (i) abundant supply of iron ore from the Dhalli-Rajhara deposits in the Drug area, (ii) manganese ore supply from Balaghat and Bhandara mines, (iii) limestone and dolomite from nearby sites, (iv) coal from Korba, Jharia and Bokaro mines.

Some of the special features of the plant are (i) a Sintering Plant of nearly a million ton capacity, (ii) a welded blast furnace construction (the first of its type in India) with high top pressure operation, (iii) special stationary open hearth furnace for a very high rate of production. The details of the plant and its production capacity have been shown in Table II. The blast furnace practice in Bhilai has so far been very good e.g. maximum production of 1350 tons of foundry pig even without using sintered burden and production of low-silicon low-sulphur basic iron.

(F) DURGAPUR STEEL PLANT[9]

The Durgapur Steel Plant is the youngest in the family of the steel plants in the public sector. The plant is situated about 117 miles west of Calcutta by the side of the Grand Trunk Road and also near the main line of the Eastern Railways. Reasons for locating the steel plant at Durgapur were (i) proximity to the coking coal reserves of Jharia and Raniganj fields, (ii) transport facilities by rail and road, and (iii) availability of water and power supply from the D.V.C.

Some of the special features of the Plant are (i) a Coal Washery (360 tons per hour) the middlings of which will be used for the Durgapur Thermal Power Station, (ii) a large Ore Blending Yard, (iii) a Desiliconizing Plant capable of reducing silicon from 1·3 to 0·7% from about 2,500 tons of pig iron per day, (iv) a Wheel and Axle Plant, and (v) a large Central Research and Control Laboratory with a Technological Block and nine different Plant Laboratories.

Some other details of the plant and its production have been given in Table II.

SOME RECENT TRENDS IN IRON AND STEEL INDUSTRY

From the dressing and preparation of raw materials to the shaping into finished products, there has been in recent years quite a few new developments some of which may in the near future revolutionize or substantially modify the existing practices of making and shaping steel. Space does not permit me to describe even briefly all these recent methods in this address. I propose therefore to take some of the more important developments which have in recent years been very well established and which with some modifications may well be adopted in the iron and steel works of this country.

(1) PREPARATION OF RAW MATERIALS

(a) Sintering of ore—It is often not realized how a careful preparation of the raw materials may affect not only the quality of a given product but also the speed of its manufacture. The raw materials for a blast furnace for example, are iron ore, coke, limestone and air. By replacing the iron ore of different grades and sizes with a suitable self-fluxing sinter in which the carbonate flux has been converted into an oxide flux, by maintaining constant humidity and by providing pre-heated blast with or without enrichment of air, the production of blast furnaces can be increased by 15 to 40% and in some cases by even a higher figure. This has been demonstrated in recent years in the blast furnace practices in several countries, particularly in U.S.S.R. In India the quality of limestone and coke is not so good as that of her iron ore. Considerable improvement in the quality and output of pig iron can be effected by setting up a suitable sintering plant in the iron works. The TISCO and also the Bhilai Steel Project have already incorporated a sinter plant in their Blast Furnace

TABLE II

SHOWING THE COMPOSITION AND THE PRODUCTION OF THE THREE STEEL PLANTS—ROURKELA, BHILAI & DURGAPUR

	ROURKELA	BHILAI	DURGAPUR
		Composition	
Coke Ovens ...	3 Batteries of 70 ovens each.	3 Batteries of 65 ovens each.	3 Batteries of 78 ovens each.
Blast Furnace ...	3 of 1,000 tons capacity each.	3 of 1,135 tons each.	3 of 1250 tons each.
Steel Melting ...	2 Mixers of 1,100 tons each. 3 L-D Converters of 40 tons each. 4 B.O.H. furnaces of 80 tons each.	1 Mixer. 6 O.H. Fce 250 tons each.	2 Mixers. 7 O.H. Fce (Basic) 200 tons each. 1 O.H. Fce (do) 100 tons each.
Rolling Mill ...	1 Blooming and Slabbing Mill. 1 Heavy Plate Mill. 1 Continuous Strip Mill. 1 Cold Rolling Mill with two sets of stands.	1 Blooming Mill 45·2″. 1 Rail and Structural Mill. 1 Merchant Mill.	1 Blooming Mill. 1 Intermediate Mill. 1 Medium Structural Mill. 1 Merchant Mill. 1 Continuous Billet Mill. 1 Wheel Tyre and Axle Plant.
Power Plant ...	75,000 KW.	24,000 KW.	15,000 KW.
Special Features	(i) Fertiliser Plant using bye-product N_2 from O_2 plant and H_2 from Coke Oven Gas. (ii) L-D process of Making Steel.	(i) Million ton Sintering Plant. (ii) First Blast Furnace in India with high top pressure operation.	(i) Coal Washery of 360 ton/hr. capacity. (ii) Desiliconization of pig iron in ladles by oxygen.
		Production	
	Plate 3/16″ and above 200,000 tons Sheets and Strips (Hot Rolled) ... ... 300,000 ,, Sheets and Strips (Cold Rolled) ... ... 170,000 ,, Tin Plates ... ... 50,000 ,,	Rails ... ... 110,000 tons Railway Sleeper Bars ... 90,000 ,, Heavy Structural Section ... ... 284,000 ,, Rounds (7/8″-3″) ... 121,000 ,, Flats (2″-5″) ... ... 15,000 ,, Billets for re-rolling ... 150,000 ,, Pig Iron ... ... 300,000 ,,	Heavy Forging Blooms 10,000 tons Merchant Section ... 240,000 ,, Forging Billet ... 60,000 ,, Sleeper Bars ... ... 60,000 ,, Light Section ... 200,000 ,, Forging Blooms ... 30,000 ,, Wheels and Tyre ... 28,000 ,, Axles ... ... 12,000 ,, Billet for sale ... 150,000 ,, Pig Iron ... ... 350,000 ,,

Departments. Under Indian conditions a sinter plant is more useful than an ore blending plant. Sintering of iron ore mixed with lime and other materials appears to be a very fruitful field of investigation which would considerably help to speed up production in this country and at the same time help to reduce consumption of coke. This dual advantage of increasing production and of decreasing coke consumption would of course be achieved at additional capital cost for the sinter plant but this cannot be avoided if the speed of iron production is to be increased during the Third Plan period.

Apart from the above advantages, sintering also helps to make usable more of fine materials (ores, blast furnace dusts and lime) in the furnace. This is particularly important, because with our increasing iron making capacity, production of blast furnace dusts and other fines would increase considerably. Moreover it is not unlikely that the alumina-silica ratio of the fine ores might be more favourable than that of the lumps.

Only a few years ago, it was believed that there was an optimum proportion of sinter usable in the burden for maximum economic operation. In recent years, however, it has been generally accepted that remarkable increase in pig iron production and/or decrease of coke consumption can be achieved with 100% sinter burden. In U.S.S.R. for example, 85 to 90% sinter burden is quite common and the sinter plant capacity in Russia is planned to be increased so that the use of 100% sinter in the larger integrated steel plant and an average of about 90% in other plants is feasible. Similarly, use of sinter in U.S.A. has been increased from about 38 million tons in 1955 to over 60 million tons in 1958. In U.K. the sinter production which was about 9 million tons in 1958 is expected to be nearly doubled in 1962. There is no doubt that there will be considerable increase in the use of sinter in this country also. And because of its many advantages the use of progressively increasing amounts of sinter may be safely recommended for adoption during the Third Plan period.

(b) Blending and Washing of Coal—Our country has insufficient reserves of good coking coal. Besides, the coking coal has high ash. Hence blending and/or washing of coal have become imperative for prolonging the life of our coking coal reserve.

Washing of coal not only decreases the ash content of the coal but improves somewhat its coking quality. Nearly 10 million tons of coking coal per annum will be required for use in the iron and steel plants at the end of the Second Plan period. Of this 7 million tons of washed coal will be supplied by five new washeries at Kargali, Dugda, Bhojudi, Pathardih and Durgapur.

The rejects from the washery sometimes contain nearly 50% of fuel matter. The amount of rejects from the Durgapur washery alone is expected to be about 450 tons per day. This is a great loss unless some suitable uses are found for utilization of their thermal value.

(c) Conditioning of the blast, and oxygen-enrichment of air—We should not lose sight of the fact that a major constituent of the raw materials for pig iron production is air. More than 2·5 tons of air are pumped in every minute in a blast furnace producing 1000 tons of pig iron per day. Oxygen, moisture and carbon dioxide are the constituents in air which react with coke to form CO and H_2. The reaction of coke with O_2 is exothermic while its reactions with H_2O and CO_2 are endothermic and hence the thermal deficiency is usually made up by enhanced blast temperature (for example 1 gram of moisture per cu. meter of blast requires about 9°C higher blast temperature for a 1000 ton furnace). Not long ago there was a good deal of endeavour at keeping the blast at a constant low level of humidity and thereby cutting down the thermal requirements in a furnace. Recently, however, the trend has been more or less just the reverse, that is, to maintain humidity of the blast at a constant higher level; the reason being that once the thermal deficiency is made up by higher blast temperature, the concentration of CO resulting from the reaction of H_2O and C and also the H_2 produced increase the efficiency of reduction of ore in the shaft thereby increasing the rate of production with the same coke rate.

In connection with the control of moisture content of the blast, investigation on the effect of hydrogen would be of great theoretical and practical interest. It has been found that with moisture of about 25 gm/m^3, nearly 40 to 70% of the hydrogen take part in the reduction of ore and escape as steam. The uniformity in operation of a furnace with steam injection in the blast is indirectly tied up with the extension of the oxidation zone. It is suggested that the steam content should not exceed the maximum natural humidity of the blast in a given locality. More than 90% of the pig iron production in U.S.S.R. are operated with blast of higher constant humidity and higher temperature (1000°C).

Another way of conditioning the blast is by injection of oxygen. It has been well established that with oxygen enrichment there is a considerable increase in the production rate and decrease in the coke rate. A reduction in the coke rate produces corresponding reduction in the amount of ash and therefore a reduction in the amount of limestone required to flux that ash, reduction in the heat requirement to smelt and flush that slag and hence a further reduction in the coke rate; the advantages are therefore cumulative. The theoretical coke reduction of 60 lbs. per ton of pig iron for example have been found to effect actual coke reduction of nearly 100 lbs per ton due to this cumulative effect. It is believed that the U.S.S.R. was the first country to apply oxygen enrichment of the blast on an industrial scale in 1939. In the production of pig iron under a constant gas volume per unit time, the increase in productivity (r%) can be calculated from the equation[10] :

$$r\% = \frac{W_2 - W_1}{W_2(100 + W_1)} \times 10^4$$

where W_1 is the initial oxygen percentage including the oxygen of the moisture in the blast and W_2 the oxygen percentage after enrichment of the blast. The volume of the enriched blast necessary in this case amounts to the following as a percentage of the original volume :

$$W = \frac{W_1 \times 10^4}{W_2(100 + W_1)}$$

It has been suggested that oxygen enrichment by its addition to the suction boxes of the blower is preferable. It has also been suggested that the enrichment should be effected by small initial doses, particularly in the case of carbon hearth. It may incidentally be noted that installation of a large oxygen plant is necessary for enrichment of the blast. For example, for a 1000 ton furnace, one needs a 100 ton oxygen plant to enrich the blast by about 2% only.

At the Weirton Steel Company[11], the four basic furnaces with an average enrichment of 1·8% use about 500 tons of oxygen per day. Upto 4% enrichment has been employed, giving about 20% increase in production. Addition of moisture is necessary to control the hearth temperature. One per cent enrichment with O_2 causes about 80 to 85°C rise in blast temperature and to nullify this rise 5 grains of moisture per cubic foot is necessary. At the Jones and Laughlin Steel Corporation[12] with 7 grains/cft. of moisture and 2·5% oxygen enrichment the production increased by about 11·5% and coke consumption decreased by about 117 lb/ton. From the data so far available from various sources it appears that a ton of additional O_2 added to the blast produces an additional ton of iron.

It is obvious that under Indian conditions the investigation of oxygen enrichment offers a very good field particularly because it offers the dual advantage of cutting down the rate of coke consumption and of increasing the rate of pig iron production without entailing much additional capital cost.

(d) High top-pressure Operation in Blast Furnace—A pressure of about 5 to 15 psi has been used with advantage in many blast furnaces in USA and USSR. Although for some reasons (mechanical difficulties, leakage troubles etc.) high top pressure operation has not been adopted in all areas with equal enthusiasm, actual operational data prove conclusively that production with a given coke rate can be considerably increased under high top pressure. This is particularly true with a high sinter burden and a high humidity blast. In recent years, high top pressure process has spread considerably. Nearly 90% of the total pig iron in USSR are produced by this process with high top pressure. In comparison with the usual practice, the high top pressure working has resulted in increase of output by 5 to 8%, decrease of coke consumption by 5% and reduction of dust loss by 20 to 50%. Assuming a constant dust loss, the possibility of increasing the through-put rate of a blast furnace may be computed from the equation[13] :

$$r\% = \left(\frac{P_2}{P_1}\right)^{0\cdot4} \times 100$$

where P_1 and P_2 represent the average gas pressure with standard conditions for blast furnace operation.

High top pressure process reduces appreciably the cost of gas cleaning, because it effects nearly 80 to 90% reduction in the energy consumption in the subsequent processes.

(2) PRE-TREATMENT OF IRON

Treatment of raw materials not only considerably improves the quality of pig iron but also raises the speed of its manufacture. Similarly treatment and conditioning of raw materials for steel plant considerably improve the quality and speed of production of steel. The metallurgical load during steel making, be it in the open hearth furnaces or the L—D converters can be appreciably reduced and hence the speed of production appreciably increased if some of the elements, particularly silicon and phosphorus in the pig iron could be partially removed prior to its charging into the furnace. The benefits of reducing the metallurgical load are cumulative. Because, not only the amounts of impurities to be removed in the furnace are less but the quantities of lime and ore to be added and hence the slag volume formed are less, the rate of heat transfer increases due to lower slag volume, the fuel consumption decreases and the life of the refractory lining increases.

Addition of pure oxygen may be carried out either—

(i) In a blast furnace runner or channel specially prepared from porous bricks through oxygen is bubbled, or, (ii) In transfer ladles in which oxygen is lanced or jetted either during filling of the ladle or otherwise, or, (iii) By treatment of iron in rotary vessels with oxygen, thus minimizing composition- and temperature-gradient in the body of the metal and promoting early slag formation and better slag-metal contact, or, (iv) By lancing and jetting oxygen into 300/800 tons active mixers.

Although the reactions are fundamentally the same in all the above cases, the speed of operation and also the results may significantly be different depending on—

(i) the efficiency of mixing, (ii) early formation of fluid slag, (iii) intimacy of slag-metal contact, (iv) variaton of the extent of heat conservation due to exothermic reactions, (v) the initial and final temperatures of the metal and so on.

From thermodynamical consideration it may well be expected that for a high Si-iron, as in India, a low velocity jet at the initial stages will be more efficient due to greater speed of surface reaction (with higher Si concentration) and higher rate of rise of temperature. With progressive desiliconization, the jet velocity may be increased to obtain greater depths of penetration leading to shorter blowing time and reduced thermal losses.

Some relevant data with regard to the above processes are given below:

(i) Blast furnace runner pre-treatment at the Moyenvre Works of Wendel et Cie, France, in conjunction with IRSID[14,15].

The Si of metal varies from 0.3 to 1.6%. The 18 feet channel is above a pit wherein the oxygen distribution equipment is located. Lime and scale are added from two hoppers above in the proportion of about 8 lbs/ton and 24 lbs/ton respectively. To facilitate mixing, the metal is made to fall 2 feet before entering the channel. About 30 tons of metal are treated in 5 to 6 minutes. The rate of oxygen flow through the porous bricks is about 280 cft/min. and is consumed to the extent of about 60 cft/ton. The Si is reduced by about 40 to 50%. The overall temperature rise is about 40°C to 65°C inspite of a fall in temperature of about 15°C due to metal drop in runners. The slag formed contains about 5 to 6% iron and the iron loss is about 1.0 to 1.5%. The process is characterized by almost complete absence of fumes. It does not interrupt flow of metal to the steel plant and has a high melting efficiency and low oxygen consumption. Investigations under Indian conditions with high Si-iron may well lead to fruitful results.

(ii) Ladle pre-treatment.

This is conducted in ladles varying from 20 to 60 tons. Limestone, mill scale or spar additions may be made depending on the nature of the metal. About one-third of the limestone is laid at the bottom of the ladle and the remainder during pouring. Oxygen is introduced through $\frac{3}{4}''$ dia. steel lance at a pressure of 180 lbs/sq. inch, the flow rate being about 15 cft/min. The process takes 20 to 40 minutes and causes appreciable rise in temperature. For example, oxidation of 0.7% Si produces rise of temperature of about 210°C. Additions of scrap including broken ingot moulds to the extent of 20 to 25% of the metal are easily made to control the temperature rise, which may be 100°C to 150°C. Oxygen efficiency is fairly high and nearly 80% of Si and Mn are removed. Sometimes oxygen-steam mixtures are used to minimize fume formation.

(iii) Rotary Process.

The Kaldo Rotary process is highly efficient for phosphorus removal due to earlier formation of basic slag and better intimacy of slag-metal contact. This process is more suitable for high phosphorus metal.

(iv) Active Mixer pre-treatment[16].

This process has tremendous potentiality under Indian conditions and if carried out in mixers of 300 to 800 tons capacity, is capable of reducing metalloid content of the blast furnace iron by about 20%, helps to utilize different types of scrap and ensures a steady flow of iron of uniform composition to the open hearth furnace. Both high-silicon and high-phosphorus metal have successfully been treated in active mixers. Due to the large capacity of a mixer and controlled rate of oxygen and scrap addition, temperature rise can be controlled without any damage to the lining of the mixer or its roof. In a typical trial the average oxygen consumption was 250 cft./ton, equivalent to about 3.12 cft. per 0.01% Si per ton of pig iron. Iron ore and limestone are added to form mainly a monobasic slag containing about 32 to 36% SiO_2, 34 to 37% CaO and 7% Fe. The mixture of oxygen and steam also has been tried successfully. Thus, desiliconization in an active mixer is an industrially feasible process. It is capable of supplying metal with low and uniform Si content. The heat generated can be used to melt scrap of different shapes and sizes and the yield can also be improved by additions of ore. Iron content in slag is low because the reactions may continue even after lancing. Life of refractory is long and no new capital expenditure is required for installation of additional plants.

OXYGEN IN STEEL MAKING[17]

The growth of oxygen consumption in iron and steel industries during the last few years has been very rapid. For example, in the last ten years oxygen-ingot ratio that is the amount of oxygen used per ton of ingot has increased 300 times. Apart from the use of oxygen in blast furnaces and for pre-treatment of pig iron, oxygen is used in steel making for combustion purposes in open hearth furnaces and for lancing and jetting in L-D converters.

Flame injection is effective in furnaces working at or close to maximum firing rates. Oxygen is usually introduced as a high velocity stream directly below the atomized liquid fuel leading to (i) increase in firing rates by about 10 to 25%, (ii) maximum rise of temperature and oxidizing capacity in the lower region of the flame, (iii) better heat transfer to the bath and (iv) minimum risk of contact of the high temperature zone of the flame with the roof. Production rates may increase by 10 to 15% with fuel savings of 5 to 10%. The consumption of oxygen may vary from 200 to 500 cft./ton.

The most spectacular success in recent years has been the roof jetting practice in which oxygen replaces some of the normal ore additions, the extra heat produced being absorbed in the melting of scrap. The rate of oxygen addition is about 100 to 300 cft./ton of metal. The operation is usually continued for 3 to 7 hours with as many as 3 jets in each furnace without producing any deleterious effect. At Weirton Steel Corporation[18] with a 530 ton open hearth furnace and a charge of 85% blown metal and scrap, a melting rate of about 100 ton/hr. was obtained with about 700 cft./ton of oxygen fed from three jets.

THE L-D PROCESS

Inspite of the many advantages of making steel by the open hearth process, it is well-known that the open hearth furnace is highly inefficient both in respect of heat transfer and rate of oxygen introduction into the bath. Consequently the tendency in the modern steel plants in recent years has been towards incorporating the salient feature of the L-D process (addition of oxygen below the surface of the metal by jetting) in the open hearth practice. The L-D process can not only produce steel of good quality comparable to (even superior to) that of the open hearth, but the process in recent years is proving quite versatile in the production of both low- and high-carbon steel (upto 1% carbon). This has been possible due to the rapid analysis of Si content of the hot metal and accurate metering of the oxygen thus enabling one to catch the carbon at the desired level. Among the products which have already been made are seamless tubes, structural steel, rails, ball bearing and crankshaft steels.

Suitability of the process for producing steel with very low phosphorus, sulphur, and nitrogen is of major importance (S upto 0.015%, P upto 0.01% and N_2 upto 0.002%). The cost of oxygen is not the decisive factor in the selection of the process because in a modern open hearth with roof jets and with a high production rate of about 45 ton/hr., the consumption is about 900 cft./ton while in the L-D process with an average production rate of about 85 ton/hr., the consumption of oxygen is about 1500 to 1800 cft./ton. Other relevant recent data from Jones & Laughlin[19] are given below:

Each heat, 82 ton ; melting rate 86.8 tons/hr. ; blowing time per heat, 21.8 minutes ; oxygen used, 1515 cft./ton ; hot metal to scrap ratio, 70/30 ; yield, 92.8% on the average ; average hot metal analysis, Si, 0.9 to 1.7%, Mn, 0.4% to 0.5%, P, 0.125%.

The Rourkela Steel Plant is the first steel works in India where steel will be made by the L-D process. There is every possibility that in future this process will be increasingly adopted in India, because the scrap problem here does not justify a hundred per cent production of steel only by the open hearth process.

Low-shaft Blast Furnace—

In Germany and some other countries where metallurgical coals are not available iron is being made in low-shaft blast furnace using non-metallurgical coals and producing 50 to 150 tons per day. Although India has huge deposits of iron ores which are of good quality and fairly well dispersed, reserves of coking coals of metallurgical grade are meagre and located in one part of the country. India should therefore make an attempt to manufacture pig iron in low-shaft furnaces as is being done in Germany. The Council of Scientific and Industrial Research have therefore to be praised for deciding to test the practicability of adopting this method in India. A 15 ton pilot plant has been already installed at Jamshedpur and since February 1959 the work has been in progress under the supervision of Dr. A. B. Chatterjee, one of the Assistant Directors of the National Metallurgical Laboratory, who was sent to Germany by the Government for special training in low-shaft blast furnace practices. The progress of this laudable enterprise is being watched with keen interest by all of us. The pace of development of Indian Iron and Steel industry will be quickened if the results of the investigation are found to be favourable.

RESEARCH AND DEVELOPMENT IN IRON AND STEEL INDUSTRIES

I have already indicated that iron is the one single metal that has played the most important rôle in shaping man's destiny on this planet and steel is the one single alloy that is at the base of all his industrial activities. This country has, therefore, launched on the great task, the great adventure of building her basic industry of iron and steel, as fast as she possibly can. Research and Development come into the picture not only as a "must" for the maintenance of high quality products but also for the attainment and acceleration of the speed with which that quality can be manufactured.

In the field of science and technology including the technology of iron and steel, hundreds of instances could be cited where apparently unresolvable problems have been solved through research. New ideas which initially appeared very difficult to be realized have been actually realized and found to revolutionize an entire industry. For instance, Bessemer steel was considered to be somewhat inferior to open hearth steel primarily because of its high nitrogen content (due to the fact that air is blown through molten pig iron in a converter). The obvious solution would have been blowing of oxygen instead of air. But this suggestion of blowing pure oxygen instead of air through a converter would have appeared, only a few years ago, to be fantastic. To-day it is well-known that the oxygen steel making process has not only produced steel low in nitrogen but stands as a serious rival of the basic open hearth process of making steel and we shall not be surprised if in the next generation, major portion of the steel is produced by some form of pneumatic process rather than the basic open hearth process.

It is often believed that in a large scale operation, such as making of iron in a blast furnace or making of steel in a basic open hearth furnace, the variables are so many and the exact quantitative informations are so difficult to obtain and corelate that it is well-nigh impossible to put the technology of iron and steel making on a scientific foundation. Although this belief could somehow be justified a decade ago, it is my strong feeling that with the development of refined instrumentation technique and availability of other physico-chemical data on slag-metal reactions, and with the feasibility of measurement and corelation of different variables, even a large scale operation can be controlled with a fair degree of precision. May I in this connection quote Lord Kelvin :

> "I often say that when you can measure what you are speaking about and express it in numbers, you know something about it ; but when you cannot measure it, when you cannot express it in numbers, your kowledge is of a meagre and unsatisfactory kind ; it may be the beginning of knowledge, but you have scarcely in your thoughts, advanced to the stage of Science, whatever the matter may be."

And I wholly agree with the following statement of Dr. G. P. Chatterjee[20] :

> "To any mature scientific mind trained in the fundamentals of Physico-chemical laws, an iron and steel plant is potentially still a wonderful laboratory for investigations and a storehouse of new knowledge."

It is not my intention to go into any details or even to suggest some of the potentially fruitful fields of investigation in an iron and steel plant.

We have now in our country sufficient number of talented scientists and technologists who, given opportunity and encouragement, are capable of solving any difficult problem facing the iron and steel industry. For example, the melting rate to-day in a modern basic open hearth steel plant varies from 35-40 tons/hr. In India the melting rate is sometimes as low as 15-20 tons/hr. Certainly by exercising a little more effort and control, by adopting some of the improved practices established elsewhere and by undertaking research and development work with special reference to local conditions and indigenous materials, the production rate can be substantially increased.

True it is that our national wealth does not permit a large quantum of capital investment on research compared to USA and USSR where sometimes 5 to 15% of the capital investments in an industry are spent on development, research and control. But it may not be too much to expect from our planners that at least 1% of the capital investment for the basic industry of iron and steel be allocated to development, research and control work, because such investment is bound to yield rich dividend in the form of higher rate of production and/or better quality of products. In this connection I would like to quote Dr. C. D. Deshmukh, former Finance Minister[21] :

> "......in an under-developed country like ours, we cannot but look forward to some immediate results which may help to raise the national wealth. . . . It is true we cannot plan discovery but we can surely plan the favouraeble conditions in which discoveries can be made. With limited funds at our disposal we must repeat fundamental work predominates, as in the case of University laboratories."

It is desirable that a nucleus of iron and steel research and development programme should be initiated and sustained in the public sector. I would like to conclude this address with the following few words :

The standard of living in India is already very low and to add to this her population is on the increase. Our leaders have therefore been confronted with an uphill task of liberating the masses from hunger and poverty. In this task research may not only enable us to discover new knowledge and new technique but may show us new ways for overcoming difficulties and accelerating production which alone can lead to a higher standard of living.

With the installation of the three large iron and steel works in the public sector within the second five year plan period, industrialization of India will take a definite and practical shape. Iron and steel are the bases for all industries including agriculture. Supply of these materials in adequate quantities is sure to start a sort of "chain reaction" in all our productive activities. Moreover, India being an under-developed country, there exists here immense scope for setting and developing varieties of industries for the manufacture of both capital and consumer goods. With the progress of industrialization, demand for iron and steel will continue to grow. It is true that we are handicapped by inadequacy of finance and dearth of trained man-power. But we have been receiving substantial help in these matters not only from USA, Canada, UK and the Continent, but also from USSR, although the latter's political ideology is different from ours.

In many respects such as poverty, over-population, food shortage and non-existence of large scale industries conditions in India are comparable to those in China. But despite all these obstacles China has been steadily developing her iron and steel industry during the last ten years and is reported to have produced eleven (eight?) million tons of steel in 1958 and thus has surpassed India in this regard. Consequently there is no room for complacency nor for satisfaction with what has so far been achieved by us. Indeed, a formidable task lies ahead of us in our forward march towards increased production of this important commodity.

I have, however, no doubt in my mind that with full utilization of our mineral and financial resources, with proper application of planning and technological experience we have already gained, with the co-operation of our technical personnel and industrial workers, and with the emotional support of our people, this basic and vital industry of iron and steel which has now been placed on a firm footing and which is expected to produce about ten million tons of steel by the end of the third five year plan will continue to grow from strength to strength and will help many other industries to grow and develop side by side with it.

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24th ,,	1937,	Hyderabad	16	8	0
25th ,,	1938,	Calcutta	30	0	0
26th ,,	1939,	Lahore	20	0	0
27th ,,	1940,	Madras	27	6	0
28th ,,	1941,	Banaras	30	4	0
29th ,,	1942,	Baroda	25	8	0
30th ,,	1943,	Calcutta	19	8	0
31st ,,	1944,	Delhi	18	0	0
32nd ,,	1945,	Nagpur	18	4	0
33rd ,,	1946,	Bangalore	21	4	0
34th ,,	1947,	Delhi	23	2	0
35th ,,	1948,	Patna	23	0	0
36th ,,	1949,	Allahabad	21	12	0
37th ,,	1950,	Poona	23	12	0
38th ,,	1951,	Bangalore	27	12	0
39th ,,	1952,	Calcutta	32	6	0
40th ,,	1953,	Lucknow	36	0	0
41st ,,	1954,	Hyderabad (Deccan)	28	0	0
42nd ,,	1955,	Baroda	33	3	0
43rd ,,	1956,	Agra	36	2	0
44th ,,	1957,	Calcutta	35	6	0
45th ,,	1958,	Madras	39	4	0
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